THE KINGDOM OF THE HEAVENS

THE KINGDOM OF THE HEAVENS *Some Star Secrets*

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INTRODUCTION

Most thinking people aspire at times to get away from the military or monetary controversies which characterise our "idealist" times. They long to see in the dreary sky things other than pounds, shillings, and pence. To them, the heavenly vault offers magic springs to slake their thirst.

Of course, there are novels. Those glittering fictions are often modelled too narrowly upon meagre human realities—Love has been surrounded with poetry by Art, and with ecstasy by Nature, so that in the end it has become a little thing of enchantment. Yet we cannot claim to lock up all ideals and mysteries within its charming but narrow circle. We must have other enthusiasms.

Fairy tales? They are commonplace in comparison with what science can reveal to us. What are the wonders of *The Arabian Nights,* even the miracles attributed to the gods by ancient mythologies, besides the telephone, X-rays, stellar spectroscopy, and the audacious mensuration of celestial spaces?

Then whither shall our thirsty hearts turn, if, like Baudelaire, they long to "plunge into the Unknown to find something new"?

Where shall we look for that sublime thrill, that unique pleasure in the New? Not in arts and letters, however fine, for past ages have equalled them, and they are but based upon unchanging human nature. Not in the world's political, social, or "economic" changes (vile word!); for ten thousand years they have moved in the same vicious circle.

There remain the sciences, which every day bring forth unexpected fruits. There remains in particular the most finished of the sciences, which most surely foresees phenomena of the future, the most disinterested of sciences, which dreams best because it reveals to us the greatest, strangest, and most distant things: the science of the stars. Stars are adorable because they resemble those chimeras for which hopeless love seeks in vain. It is good to raise our eyes and thoughts towards the lights which are far away —too far away.

Renan one day, in order to be able to view the contingencies of the little dust particle we call the Earth more at his ease, invented the "point of view of Sirius." He is wiser, and destined to see more harmonious visions, who, *adopting the opposite* attitude, contemplates from down here the splendid forms assumed by matter and force in Sirius—or in more distant realms.

Thought is the most swift and subtle of vehicles.

Let us therefore use that craft to reach a trysting-place in the skies. The light which reaches us from them and which we analyse nightly at the focus of our telescope brings us pieces of wonderful news. The things it tells us, prodigious but true, raise us to heights never yet attained by the golden wings of fancy. In this book I wish to relate some of the marvels which the heavens have revealed to us recently.

Do not look for all the usual commonplaces, all the exact but ancient data found in manuals and compilations. I confine myself to what is recent and new. I shall speak, not to instruct or amuse, but to produce thoughts and even dreams, if I can.

Nor will you find in this book the usual inane vapourings concerning the beautiful sentiments evoked by the study of the skies. I do not believe in them. I have never observed them around me. And it is some time since Henri Poincaré justly proclaimed the separation of science and ethics.

From the earth, after a short inspection of our pale follower, the moon, a journey of but 93,000,000 miles brings us to the sun. Some surprising novelties have been found there of late. We shall study the singular magnetic and electric influences it exercises upon us, which, like a sort of telepathy, make us tremble to its slightest spasms. Accosting the planets in passing, we shall not fail to see the present state of the question as to whether they are habitable,

nor to ask ourselves the newly raised question as to the transmission of life from one to the other. In this connection we shall see that one of the most seductive fairy-tales from on high, about which there has grown up a thriving pseudo-astronomical literature—without a foundation, unfortunately—I mean the "canals" of Mars, are but a mirage.

Leaving our little solar colony, we shall take a leap to the stars whose temperature and physical and chemical evolution have been the subject of some splendid recent discoveries.

Thence, in our upward rush, it will be but child's-play to reach those strange ant-heaps of stars called "clusters," and finally the vertiginous spiral nebulæ which will teach us to measure the immensity of the ocean of space.

Having thus sounded the sidereal abysses we must find an anchorage for the earth and its movements. Does the earth really rotate in the starry firmament? Is it not the latter which revolves round the earth, as Ptolemy viewed it? It is an all-important question. Since Galileo, it had been considered finally answered. We shall see that that is not the case, and that that famous prosecution comes into appeal in an almost incredibly round-about way.

If this chapter on the earth's rotation has been placed after the others, it is because it is rather more difficult.

In our stellar promenade we shall not load ourselves with a useless mathematical terminology. Let us leave that pedantic apparatus to the pedants. It will be seen, I hope, that these magnificent realities can be unveiled in every-day language without loss of accuracy, and the voyage will be all the more agreeable.

The Heavens! Ever since there have been poetic souls uttering rhymed or metred lines, many erroneous and charming things have been written about them.

It is not long ago—what are a few centuries?—that the daily movement of the heavens was explained by supposing that the stars had been nailed by some artist god to a material sphere turning round us in twenty-four hours. That sphere would have to be solid. Aristotle, indeed, had said, in effect, that its solidity was an attribute belonging to the nobility of its nature. It required some fastidiousness not to be convinced by that argument. Solid and transparent, it could only be made of crystal. When it was found that the sun, moon, and planets had not the same speed of revolution as the stars, it became necessary, in order to fix them, to have a number of other crystalline heavens, among which the seventh heaven—nobody knows why—was believed to be the abode of extraordinary posthumous felicities. The price of crystal did not worry those philosophers.

Thus the blue sky became a very complicated

machine. Alas! The celestial blue is not at all the colour of starry space, but only of our atmosphere. That little air-bubble round the earth which we breathe is so small that if, instead of becoming thinner with altitude, it remained of the same density throughout, it would be only about five miles in thickness. The total mass of the atmosphere, by the way, is only 5,000,000,000,000,000 tons, a mere nothing in the infinite. The blue sky is not much of anything.

Now, why is the blue of the firmament the colour of the Ideal? Why does it, more than any other spectacle in nature, bring into human hearts that nostalgia of the Infinite and the Perfect which has always stirred them so deeply?

Is it not due to those ancient religious legends which, from the Scandinavians to the Greeks and Hindoos, have found in the azure zenith their simple "kingdom of the heavens," their posthumous, reparative, and sadly hypothetical Eden? I am fain to believe it. From all these beautiful fairy-tales there remains a sort of atavistic fervour, even in the hearts of unbelievers. The skies are like one of those ancient yellow books from which, when opened, there comes a smell of the meadow, because some day, long ago, some ancestress pressed in it flowers to dry.

That blue sky, caused by the presence of air, and called by simple-minded poets the "infinite azure,"

is only due to a thin skin of air. The real sky, the sky which extends its silent deserts beyond the blue, is not a blue canopy spread above His Majesty Man on which a celestial decorator has fixed the golden nails of the stars. The true sky is black, a deep black of eternal mourning. The stars are not golden nails, but, maybe, stops on a blank page. . . .

Having achieved our voyage round the Universe, our circumnavigation of the Kingdom of the Heavens, we *must try to conclude*.

After having roamed in thought across starry space, at the moment of falling back on the earth, so flat in spite of its roundness, one feels haunted by the primordial mysteries of this strange world where our ephemeral thoughts must dwell for a time. When on the front of the Parthenon some disciple of Phidias had sculptured a beautiful equestrian frieze, he would, I imagine, step back for a moment to look upon his work as a whole, and would then merge his own effort in the vast equilibrium of the entire temple. Thus must the savant act in front of the universe, thus the astronomer worthy of the name. How can we, in the mysterious majesty of the physical world, ignore the problem of destiny ?

We shall, therefore, ask ourselves sincerely whether this immense harmony of the stellar firmament need only dazzle our eyes without consoling our hearts.

Without a vain despair, but without any intoxicating illusions, we shall seek the divine under material guises.

And, after all, when you are riveted to the earth, a ball weighing 13 quadrillion pounds, you may surely be allowed sometimes to indulge your soul in a winged flight towards an inaccessible dream-land.

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CHAPTER I

ON THE MOON

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THE crescent of the moon is always a pleasant object to see, especially when quite new. It is so fine and delicate that we might think it a curved eyelash fallen from the eyelid of some blonde goddess.

The moon charms absent-minded people who happen to look upwards into the air. It even interests others whenever an announcement is made that traces of life have been discovered upon it. That is what happened when the American astronomer, W. H. Pickering, thought he had found distinct traces of organised life on the moon. We shall soon see what to think of this "sensational" news.

One could write a hundred volumes—I shall not attempt it—to explain all the errors of which the moon has been the subject, though nearly all of them contain a little grain of truth.

What has not been said about the influence of the moon on the mind? To sleep in the moonlight is supposed to render people mad, or at least very fanci-

ful. If that is so, many people in the world must have been sleeping in moonlight since our friend Pierrot found out how to do it. Yet we may find some amusement in the delicious follies which the moon goddess has disseminated through our literature, with its romantic insipidities, its mythological vagaries, its sentimental incoherencies, its serenades and guitars.

In spite of the dry rigour of precise measurement, the moon, I am sure, will always be dear to the lovers of the fantastic, although it has been measured, weighed, and deprived of its ancient mystery.

That is because it exerts a strange influence upon our senses, with which reasoning has nothing to do. When moonlight showers impalpable lilac shades on the misty plain, what human being, be his head ever so highly charged with tables of logarithms, does not feel tempted to softer dreams? But the moon is particularly dear to loving hearts no doubt because her phases are as changeable as themselves. Even animals are a little "lunatic" and in every part of the world dogs bark at the moon, except in Australia, and that is because the dogs or "dingoes" in that country are without a voice.

Thanks to the admirable photographs recently taken at the Observatory at Paris, which are even superior to those taken at the great American Observatories, we know the surface of the moon nearly

as well as if we had travelled over it *alpenstock* in hand.

The voyage to the moon which has haunted so many minds is therefore almost superfluous, and that is well, because the cannon-ball proposed by Jules Verne, with its initial velocity of 8 miles a second (necessary in order to escape from the attraction of the earth), a speed acquired in 1/30th of a second, would have certainly flattened out the travellers within the shell to the shape of a thin meat patty. Jules Verne had forgotten that all sudden variations of speed in a vehicle are nearly as dangerous for the people inside it as for those in front of it.

As regards a reaction motor—based upon the principle of the sky-rocket—which has been more recently proposed to drive the vehicle as far as the moon, it is free from that objection. But it raises other difficulties, and does not solve the problem of landing on the moon.

All these projects contain a great deal of ingenuity and scientific spirit. They are an advance on the amiable Gascon fancies by which Cyrano de Bergerac proposed to travel to the states and empires of the moon. His were but poetic mechanisms which by their ethereal nature are free from the laws presiding over ordinary gravitation.

In short, as we cannot get to the moon, it is best

to bring the moon down to us and fix it upon the silvered gelatine of our astrographic cameras.

Thanks to these, the topographical study of our satellite is much more advanced than that of the globe on which we live. If lunar geography, or so-called selenography, has recently made remarkable progress, it is on account of the photographic plate, which Janssen calls "the real retina of the scientific man." By its means we are enabled to add to the æsthetic pleasure inspired by the contemplation of lunar landscapes in all those who love beautiful forms and the ravishing play of light and shadow, some precious pieces of information which show in advance the fate in store for our own earth.

For the moon, having a mass eighty-one times less than that of the earth, has cooled down much more rapidly. A large soldering-iron requires less plunging into the fire than a smaller one in order to preserve its proper temperature. The moon has traversed with great speed—in a few million years—the fatal phases in the evolution of all stars. It is, so to speak, a still-born earth.

In the course of a journey we often meet, by accident, companions given to us by chance, and yet we end by conceiving for them an affection none the less sincere for being accidental. This may be the reason why in the silent saraband which takes the roving stars towards an unknown destination we regard

our neighbour the moon with a particular tenderness. Almost alone in the universe, she does not humiliate us by her size and an importance superior to our own. It raises us in our own estimation to have in the solar group, where we cut such a sorry figure, this silent and humble follower.

To tell the truth, we do not speak here of the entire moon, but of that hemisphere which is always turned towards us, since it always makes its revolution round the earth in the same time as it rotates on its own axis.

It is well known to-day why that is so. Just as the moon by its attraction creates tides on the earth, so the earth produced tides on our satellite at a time when it still contained some liquid. The earth's mass being much the larger, the lunar tides were much greater than ours. Formerly the moon turned on its axis much more quickly than it does now. This rotation, which we may call the lunar day, was only about eight days some 56,000,000 years ago, or four times shorter than at present.

But the liquid protuberance produced on the moon by the earth's attraction, which always bulged towards the earth, would by its viscosity and friction act as a brake and slow down the lunar rotation, until it became the same length as a lunar month, as it is at the present time.

This retarding influence of the tide enables us to

solve a singular little problem which has been recently proposed.

The moon presents in its orbital movement a slight abnormal acceleration which does not agree with calculations made by the new methods of celestial mechanics. This acceleration is feeble and does not appear to exceed a few seconds of arc per century. This is very small, as we realise on remembering that an angle of one second is less than the 300,000th part of the right angle.

However small it may be, this secular acceleration of the moon's movement is real, and astronomical observations with their very precise methods have established it long ago. Laplace already had occupied himself with it at the beginning of the last century.

The new gravitational law of Einstein has recently been stated to account for this anomaly in the lunar movement, just as it explains the secular acceleration of the perihelium of the planet Mercury. But a careful examination shows that this explanation can hardly be the right one.

The real explanation seems to be as follows:

If the movement of the moon seems to be accelerated, if it seems to revolve a little more quickly round the earth, that is simply because the earth turns less quickly on its own axis, that is to say, that the sidereal day is increasing. The moon does not really go faster but our unit of time is growing.

On making the calculation we find that the friction of the present oceans on the ocean bottom is quite insufficient to account for the effect observed, small as it is. We must take into account the intense friction probably produced by the internal tide due to the more or less fluid and viscous portions of the interior of the earth.

Sir G. H. Darwin, the astronomer, son of the illustrious naturalist, has utilised this argument to calculate from the secular acceleration of the moon the value of the coefficient of viscosity of the interior of the earth. If we adopt this coefficient we find a time of evolution of the system of earth and moon amounting to several thousand million years. It is true that this number must be considerably reduced, because the earth was no doubt much more liquid in former times than it is to-day.

In any case, the secular acceleration of the moon's mean motion is completely explained if we admit that in every century the time measured by the apparent movement of the starry vault is three seconds behind what it would be if the duration of rotation of the earth had remained the same.

The daily movement of the celestial sphere—in other words, the rotation of the earth—is the clock which we use for measuring and subdividing time. On account of the retarding influence of the moon, it follows that if we had a perfect chronometer we

should find at the end of a century that it had advanced by three seconds. That is an influence of the moon which Baudelaire had not foreseen.

. . . . .

The photographs obtained with the great *équatorial coudé* of the Paris Observatory were taken with an exposure of about one second, during which the instrument follows the apparent movement of the moon very exactly. It only requires an exposure of some 10,000th of a second to obtain similar photographs of the sun.

In fact the sun is about 600,000 times brighter than the full moon. This implies that if the starry sky had over its full surface a uniform brightness equal to that of the full moon, we should yet obtain an illumination six times less than that of the mid-day sun. Our first impression, not based upon precise photometric measurements, is certainly that the difference between the brightness of the sun and moon is less than that.

On this subject there exist many other errors. Thus, it is currently believed that the light of the moon is more blue and less yellow than that of the sun. Painters are in the habit of painting moonlit landscapes with bluish tints and sunlit scenes with yellowish tints. It is just the contrary. The sun is really much bluer than the moon, and the moon is more yellowish than the sun. The opposite impression

is due to an optical illusion called Purkinje's phenomenon, which consists in the fact that the eye becomes proportionately more sensitive to the short wave-lengths when the brightness of the sources of light diminishes. It is, therefore, because the moon is much less bright than the sun that it appears bluer. It is really more reddish. It is this illusion, and not reality, which painters represent to us. In this matter the most classical artists are impressionists in spite of themselves.

When the lunar photographs of the Observatory are suitably enlarged there is not a single object, no hill or valley, or any peculiarity of the ground which can escape our notice so long as it is from 400 to 500 yards in size. On the other hand, on our whole earth, in the polar regions and in all the continents, except Europe, there are stretches of country tens or hundreds of times larger which are unknown to geographers.

There is, of course, a limit to the enlargement of the lunar negatives beyond which the visibility of objects cannot increase, and this limit is imposed by the dimensions of the grains of the photographic plate itself.

On a first examination of the lunar photographs taken in the first quarter, for instance, we find that the fineness and modelling of the details increases as we leave the circular edge of the disc and approach the line which separates the illuminated portion from

the dark portion, a line which is called the "Terminator."

The reason is that along this terminator the sun is rising and the smallest roughness of the surface of the moon casts enormous shadows which give every detail of the relief.

These projected shadows are as if cut out with a knife, and are much sharper and more definite than those of our terrestrial landscapes. Why? Firstly, because air and water have long ceased to exist on the moon and the slow process of erosion and softening of angles produced by these agents has remained incomplete on the moon. Everywhere the summits of mountains and depths of valleys have retained the crude nobility of their first lines. Secondly, there is on the moon no atmosphere which, as here on earth, would diffuse the sun's light and give a soft and mellow character to the shadows and peaks of distant landscapes. This absence of a sensible lunar atmosphere has been demonstrated by several methods, notably by the spectroscope and by the occultations of stars by the moon's disc, which occur with extraordinary suddenness and not gradually, as would be the case if there were an absorbing and refracting atmosphere. Hence this crystal clearness, and the sharp contrast of light and shadow which imparts their strange beauty to the lunar landscapes.

In the regions away from the terminator the sun is

higher above the horizon, the projected shadows are shorter and the landscape appears flatter. That is why photographs of the full moon, and indeed its telescopic appearance, are much the least interesting.

The terminator of the first quarter, which to the naked eye appears a straight line, is extraordinarily broken up when seen with the powerful vision conferred upon us by photography. In some places the shadow encroaches profoundly upon the illuminated portion. Close by, the latter advances boldly into the night in headlands of disconnected light. In other places we see isolated points, veritable oases of brightness surrounded by shadow.

In observing these we are present at a sunrise upon the mountains of the moon. These luminous points are summits already gilded by the sun, while their neighbouring regions are still plunged in night. Thus, at Geneva, when it is still night, Mont Blanc is seen to glow in a rosy light from the sun.

We can therefore, at a very small cost, watch on the moon that *alpenglühn* for the sake of which Tartarin made his memorable ascent of the Righi.

Many of the lunar mountains are very high. Their altitude is easily measured by various methods, particularly by the length of the projected shadow. The highest is Mount Leibnitz, near the South Pole of the moon, which is about 24,000 feet high, or about as high as the Himalayas. The moon, therefore, is

proportionately much more irregular than the earth, whose diameter is four times as great.

It is also much more volcanic. Its thousands of craters have in general much greater dimensions than the greatest volcanic orifices of the earth. Some of them are hundreds of miles across.

These lunar rings are constructed in a uniform manner, vast circular funnels, very similar to those seen in the Colosseum and the amphitheatres of Nîmes. They differ from these by the gentle slope of their walls outward, and their sometimes very steep slope inwards, amounting to as much as 45°, towards the flat bottom of the centre of the funnel. Often we see in the centre of the circle an isolated peak generally less high than the rim of the crater. Certain lunar circles are of enormous depth, which we can also measure by the shadows cast. Thus, the crater Curtius has a depth of 21,000 feet, and the beautiful crater of Copernicus a depth of 10,000 feet. The latter is 56 miles across.

There are several tens of thousands of craters of all sizes distributed over the surface of the moon. Many of them have names, usually the names of scientific men, mostly astronomers, the majority of whom would otherwise have been forgotten long ago, because there have never been thousands of eminent astronomers on the earth.

The moon is therefore in reality the lunar Pantheon.

Equity has not always presided over these names. Thus, in the seventeenth century Riccioli, a very mediocre, but influential astronomer (as it happens sometimes), gave his own name to a magnificent lunar circle, while he gave the name of Galileo to quite an insignificant crater situated close by. And so in looking at a map of the moon we might imagine ourselves on earth.

The origin of the lunar craters has been much discussed, and certain very fanciful hypotheses have been advanced. That of a ballistic formation which attributes the craters to the fall of numerous shooting stars must be set aside for a variety of reasons. It seems well established by the profound studies of Loewy and Puiseux that they are due to the pressure of the incandescent interior of the moon, which raised them up at the points of least resistance. Then as the inner mass was withdrawn, the centre of the dome collapsed.

Among these circles, which are at the present time volcanically extinct, there are some of more or less recent formation. The photographs show that the younger ones encroach upon the wall of the neighbouring circles. For in geology, as also, I am told, in human society, the young and vigorous elbow out of their way those whose resistance has been enfeebled by time and age.

Among the crowd of craters the most remarkable

lunar features are the large dark patches which are really plains, but which are called seas, although no trace of water has ever been discovered. Thus, we have the Sea of Serenity, of Tranquillity, of Crises, etc. We preserve these old and quaint names with a sort of filial piety, as they have been given by our predecessors in astronomy.

On the shores of these seas we find veritable mountain chains which are called Alps, Apennines, Caucasus, and so on. These names show no lack of imagination. The summit of the lunar Alps, which is called Mount Blanc, as it should be, is only 12,000 feet high, or 4,000 less than our own Mont Blanc. Thus, once more, the hierarchy is respected.

That is the savage world in which Professor Pickering, of Harvard University, has just declared on the ground of his most recent observations that life exists. This piece of news announced to the universe, or rather to the population of the earth, by all the cables and all the waves of wireless telegraphy, has even caused some emotion in drawing-rooms, which, by the way, is much to the credit of the drawing-rooms.

What reason has Professor Pickering, whose astronomical labours are favourably known, to affirm that there is life on the distorted visage of our pale satellite? It is a fact, so says the American astronomer, that there are immense areas of vegetation which grow up in certain places with a prodigious

speed as soon as the sunlight touches them. These vast expanses of vegetation bloom quite suddenly, and as suddenly perish and disappear.

Now the recent observations of M. Le Morvan at the Paris Observatory allow us to form an opinion on this subject.

What has given rise to the news announced by Professor Pickering is the undoubted observation during each lunation of green patches, more or less mixed with yellow and white, in the lower depths of certain lunar craters with broken walls. The curious thing is that these tints are observed for a short time after sunrise when the rays fall upon these depths at a grazing incidence.

Shortly afterwards, as soon as the sun rises higher, these patches disappear. There is nothing to show that the green tints, so short-lived and localised, are produced by vegetation.. Everything in fact tends to show that they are simply due to the refraction of the sun's rays by myriads of crystals with sharp edges, and by the more or less glassy volcanic rocks which on the moon, as in certain volcanic regions of the earth, must abound in the neighbourhood of extinct craters.

This is all the more likely since, as we have seen, the sharp edges of these crystals and transparent rocks, as well as the broken edges of the craters, have not been worn away by erosion. Circumstances

are therefore extremely favourable to those colour effects of sunlight to which M. Le Morvan attributes the appearances so sensationally interpreted by Professor Pickering. It is in fact something analogous to the "green ray" of the earth. This view must be correct even without the optical proof of the absence of water and oxygen on the moon. Sometimes these green zones spread or disappear over enormous areas in a few moments. Vegetation could not possibly spread in such a manner.

Furthermore, Professor Pickering assures us that he has seen on the moon certain changes which he unhesitatingly attributes to blizzards, volcanic eruptions, fogs and mists, and clouds. There is probably nothing real behind all this.

For a long time the observers of the moon have announced brilliant points which move about, as well as more or less hazy areas, changing from one moment to another and indicating some sort of mist or cloud. Yet on comparing the photographs or drawings of these observers we find that the variations seen by them do not agree among themselves. Besides, photographs taken at intervals of a few moments show changes which, if they were real, would correspond to displacements of the moon's surface with velocities of several miles per second. The truth is that all these so-called lunar transformations are caused by the agitation and undulation of

the earth's atmosphere. The appearances correspond to the twinkling of the stars. It suffices to contemplate the image of the moon in a good telescope and its tremblings and undulations to be convinced.

In short, nothing authorises us to assume the existence of organised life on our satellite, whose surface is a thousand times more deserted and sterile than the Sahara. Aristo long ago described on the moon valleys full of flowers and peopled with dancing nymphs. Alas, we must renounce this idea, unless there are nymphs who can exist without air.

There are no inhabitants in the moon, and there is no way of getting about on it. These facts are well calculated to preserve for our satellite that proud nobility attached to objects whose beauty and perfection is not linked with any necessity.

Unfortunately this distinction must disappear as soon as we discuss the utilisation of the energy of the tides for the necessities of human industry.

If some financier were to promote a company for the exploitation of the force of the moon he would no doubt be speedily locked up. That would be a regrettable judicial error. I am in fact convinced that the remedy for all economic difficulties which trouble humanity, and the solution of the whole social question, are bound up with the moon.

It is the moon which causes the tides. Now the tides constitute an extremely powerful machine with

the movement of an alternating piston. Up to now we have not been able to harness the enormous power of this machine, but that is because we are incompetent, or rather because we are barbarians.

When humanity emerges from the ignorance which encompasses it it will certainly utilise the thousands of millions of horse-power which the tides place at the disposal of our feeble hands. On that day men, being no more under the necessity of devouring each other in order to live, will occupy themselves with science, art, or metaphysics. We shall no longer fight for interests but for ideas. The struggle will not be less ferocious, but it will have higher motives, and this can be a comfort to the philosophers, if any are left.

To inaugurate that golden age by an act of administration the French Government has recently appointed a Commission of " blue coal " in order to attack the problem of the utilisation of tides at certain points on the coast.

Poor Moon, once the refuge of dreamers of the impossible, pearly tear in the dark eye of Night, here are busy people anxious to catch your emanations and turn them into merchandise, and grind them into money in their noisy mills!

Forgive us, Selene! When everybody is rich there will be more time for dreams.

CHAPTER II

LIFE IN THE UNIVERSE

The interstellar transmission of life—Venus, Jupiter, Saturn—The Martians and their "canals"—Diffraction, illusion, and deception—Wireless telegrams from the sky—Solar storms and Hertzian waves—The plurality of inhabited worlds.

Is life an astronomical phenomenon? Certainly, if we consider some recent discoveries of biologists and physicists. For they prove, as we shall see, that life can be transmitted from one star to another.

Besides, without life and its flower of thought the sidereal universe would be as if it did not exist, and would resemble a diamond hidden in the shadow and not illuminated by any ray. Without life there would be no astronomy, because there would be no astronomers. On this account it is right to consider it even in a book dealing with the heavenly bodies.

How can life pass from one world to another? What reasons have we to think that it can exist on planets other than our own? What about the famous question of the "canals" of Mars? Such are the questions which arise.

M. Bergeret pretended that organised life is nothing but a parasite creeping over the surface of this globe. He said it because he had been cruelly hurt in his

domestic felicity. For very often the speculations of the wisest philosophers are optimistic or despairing, according to the state of their viscera. And if at the moment when he put forward that despairing aphorism M. Bergeret had seen the silhouette of Madame de Gromance he would no doubt have made an exception to his disdain in favour of at least some mammalian creature.

In reality, few things are so worthy of study as the phenomenon of life with all the riddles which it sets to science. It is true, as geology proves, that we must only consider it an extremely ephemeral and superficial accident in the thermal evolution of the earth. It is all the more interesting to find how it can have come into existence for the first time.

Powerful thinkers, from Kant to Lord Kelvin, have maintained that the germs of life may have been brought here by meteorites from a distant world. But the mechanism of this transmission remained obscure. It was thought that the perfect vacuum and very low temperature of the interstellar spaces would oppose an absolute obstacle to the transmission of living things.

Recent experiments have directed these ideas into a new channel, and removed them from the imposing but rather vague domain of speculation.

The action exercised upon many bacteria by a vacuum and by temperatures near the absolute

zero is not destructive but conservative. Extreme cold and vacuum only suspend for a very long time the vital functions of those minute living beings which normally would only last a few hours.

If they are restored to the atmosphere after years they recover instantly their germinative faculty in all its original vigour. Is not this on an infinitely small scale the true history of the Sleeping Beauty?

Interstellar space is therefore a medium favourable to the transmission of life.

As regards the mechanism by which the micro-organisms can be sent from one world to the other, recent discoveries on the pressure of light allow us to form some idea. The sun does not attract nor retain in its power any masses but those of considerable size. As their volume diminishes the well-known repulsion exerted upon them by the rays of the sun becomes eventually a preponderating force. It is even the probable cause of orientation of the tails of comets. As regards very small objects, like bacteria, whose diameter is only a few 10,000ths of a millimetre, the sun's light expels them into infinite space until they conglomerate with other cosmic dust and are attracted by some other heavenly body.

We can so understand how, from remote times, life may have been transmitted from one solar system to another. All that was required was that in some portion of the depths of the sky, in the neighbourhood

of Sirius or still farther away, a planet should exist whose atmosphere, like ours, contains micro-organisms which, expelled by the rays of the neighbouring sun, would start in their millions on their long voyage through the icy spaces of the heavens.

May we not think that in such a manner the first germ of life fell upon the earth ?

But can a simple micro-organism, once it has found a favourable place, explain the rich flowering of all the animal and vegetable forms ending in the divine brain of a Beethoven, a Newton, or Pasteur ? To this many biologists have boldly answered yes. They think that biological transformation makes it unnecessary to assume an act of creation for each of the living species. Others, on the contrary, deny this absolutely. For them evolution is only a mirage, an hypothesis full of holes. At this point our problem passes beyond the bounds of astronomy and becomes one of biology. The supporters of both opinions are no doubt excellent observers, and we do not wish to contradict anyone. Let us abstain from taking any part in this controversy, which is far from ended, and let us take refuge in our planets.

And when we are up there let us consult the facts.

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When we have proved by analogies and by extrapolations from small laboratory experiments that life is possible in worlds other than our own, it still

remains to prove that it exists. We have no right to say that life exists on other planets until we have observed it or seen its effects.

If we set aside Mars, which in this respect deserves the special study we have reserved for it, let us see what the other large planets in our neighbourhood, Venus, Jupiter, Saturn, can show us.

First of all, Venus. Although it is sometimes only 25,000,000 miles away from us, although its brightness is sometimes 130 times that of a star of the first magnitude, we do not know much about her, except that she shows phases like the moon, visible in the smallest telescope. Herein she is, so to speak, moonlike and justifies to some extent her divinely feminine name. We also know that she has no satellites and that her diameter is almost exactly the same as that of the earth. The spectroscope has revealed water vapour in her atmosphere. And that is all.

An entirely cloudy atmosphere always hides from us the surface of the planet, so that we do not know with any certainty the period of its rotation. We know nothing of what is hidden by that veil of clouds. Yet one would love to believe that life laughs and palpitates on this star which takes its name from the Goddess of Love. There, perhaps, things are not so topsy-turvy as they are here. Universal ideal governs all thoughts, and one may adorn one's head with a wreath of roses, without at the same time

putting on a crown of thorns. But nothing of this is certain. Venus remains concealed from our curiosity, and we hardly know more about it than did the ancients. For us, as for them, when it sets after the sun, it remains the evening star, so much beloved by the poets, Homer's "beautiful Hesperus." Then in the west when the evening folds its dark wings about us it lights up like a lantern the banks of the night. Seeing it there, the shepherds of the East knew it was time to take their sheep home. Hence the pretty name "The Shepherds' Star."

When, on the other hand, in the pearly dawn of the east, it precedes the rising sun, it is the morning star, the light out of the sea, the pearl which the day will soon dissolve in its shining cup.

This is all very well, but it leaves us at the same point as we were 2,000 years ago.

Jupiter. Jupiter, the king or the queen of the planets—I do not know which, and I must leave to grammarians the task of solving this astronomical problem—Jupiter, more massive than all the other planets put together, 1,200 times more voluminous than the earth, only brings disappointment to those who look for life there. The most powerful telescopes reveal on its flattened disc long white belts, parallel to the equator. In times when mythology flourished, these belts were said to have been stolen by Jupiter the god from his victims among the timid

nymphs. More prosaically, we know that they are clouds, or rather condensations of fluid substance which form the surface of the planet, a surface which is not yet solidified nor entirely connected with the movements of the incandescent nucleus.

As regards the strange Red Spot which floats among the equatorial bands, it seems to be a sort of enormous slag in the course of formation, a sort of continent, larger than the whole earth, which is gradually crystallising, and floats on the surface of a planet in a state of fusion. There is no trace of life in all that. It is hardly reasonable to suppose it possible on the surface of this planet, when we consider that no living being can suffer a temperature of 150 degrees. And the eight satellites, the eight Jovian moons, which encircle the enormous planet with their swift and unequal movements, need hardly be considered in this respect.

What about Saturn? Few details are available concerning this gold-ringed planet. Even when closest to us it is still 760,000,000 miles away. That its gigantic ring, over 170,000 miles in diameter and only about 62 miles in thickness, which surrounds it like a halo, is made up of myriads of small independent satellites, is proved by celestial mechanics and by spectroscopy. That its volume is 730 times that of the earth, that its year lasts 29 of our years, and its day 10½ days of our own, has been known for a long time.

There is nothing to indicate organised life. The Saturnian nights must be very beautiful on account of the ring, which, like a great wall of light, shines above the horizon, and the 10 moons, which chase each other without ceasing, the largest of them as large as the earth and the smallest but 60 miles in diameter.

One would like to know that inhabitants of Saturn were a thousand fathoms in height, as Voltaire assures us. It would be particularly desirable to have reasons for believing that they exist. But if that is the case, when they see that no other planet has anything to compare with those splendours which illuminate their nights, emotions of pride must stir their hearts. They must think that the rest of the universe has only been made as a poetical frame for their privileged planet. Their ideas must be deplorably "saturnicentric." Comparing one hypothesis with another, I prefer to plunge them back into non-existence.

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The planet Mars, which some time in the year roams nightly from one constellation in the ecliptic to the other, is easily recognised, first by its dark orange colour, and then by its absence of scintillation. This gives it a sort of, serenity among the twinkling and palpitation of its neighbouring stars.

When Mars is in opposition—that is to say, on the

same side of the sun as the earth, and nearly in a straight line with both—an event which occurs once a year—less than 62,000,000 miles lie between us.

Every year or so it is the fashion to speak of Mars for several weeks. Then all the papers in both worlds display telegrams announcing the performances, more or less astonishing, of the earth-dwellers who endeavour once more to communicate with this strange planet. In spite of the fluctuations of peoples' minds from foreign politics to home politics, these telegrams are read and they even attract some interest. They are discussed in after-dinner talks amid the thin smoke of cigarettes.

This is because there always has been, and always will be, in the human heart, an attraction towards the unknown, towards even that material Beyond which is marked out by the planetary worlds. Our special preference for the planet Mars is certainly partly due to its name, which makes this star singularly representative of the years we have lived through. If astrological arguments were not forbidden I should not hesitate to remark that our times are certainly under the sign of Mars, for never on earth have we seen so many Martial manifestations. I should also remark that none of the large planets is called Minerva, and I should conclude with some disillusioned aphorism concerning the slight prestige of wisdom down here, at least as far as astronomical

names can be a guide. But these considerations would take me rather away from my subject.

Several times already in the past the news agencies, those modern trumpets of fame, have announced that according to the very words of the celebrated Marconi the central stations for wireless telegraphy have registered Hertzian signals of unknown origin; which could not on account of their nature, and for reasons shown below, be attributed to any purely earthly source. This caused a grand sensation in the editorial offices, round the marble tables of the restaurants, and even among the frequenters of the most aristocratic drawing-room. It was said at once that these Hertzian signals out of space could only be signals of distress sent out by our neighbours among the planets. Doubtless it was the inhabitants of Mars who called upon us by radio-telegraphy. It only remained to find the key or the code which would enable us to translate these cryptic messages into English, or even into French.

Why, do you ask, should these messages come from Mars rather than from Venus, Saturn, or Neptune? Well, because Mars, as everybody knows, or at least, as everybody says, has shown itself long ago to be the abode of an intellectual élite which has reached a high degree of civilisation. Consequently —and here the reasoning is incontrovertible—it is natural to attribute to Mars these mysterious signals

rather than to any other planet, whence, as far as we know, not the slightest sign of organised and intelligent life has ever reached us. When in a large room there is only one other person and a wooden box, and we hear a well-known song, that song is naturally attributed to the other only person present in the room. As a rule the argument is sound, but not always, for the song might come from a gramophone inside the box, or even from a telephone concealed under the floor.

At this point in our discussion a question arises which we must clear up as far as we can with the means at our disposal.

The question is as follows :

What must we think after the recent discoveries, and precise observations of scientific men, of the peculiarities observed on the planet Mars by different observers ? What are the famous " canals " of Mars ?

It was, I believe, the Italian astronomer, Schiaparelli, who was the first, in 1877, to announce the network of " canals " on the surface of the planet Mars. Since then many observers, both in France and abroad, have confirmed and extended Schiaparelli's discovery.

In the telescope Mars has an enormous advantage over the other planets. Its surface is not, like theirs, enveloped in clouds in constant movement which hinder observation. The atmosphere of Mars is of

slight density. When a star is occulted by the disc of the planet it disappears very suddenly behind that disc, which would not be the case if the light of the star underwent a perceptible refraction in the Martian atmosphere. These circumstances allow us to observe the surface of Mars with great clearness, and to distinguish a certain number of topographical peculiarities on the existence of which astronomers are in agreement. Among these we have the polar caps, very white, like those of the terrestial globe, probably formed by ice or snow, and with dimensions varying according to the season and according to the intensity of the sun's rays.

Besides these polar caps, with their characteristic fluctuations, according to the season, all the observations record on the surface of Mars certain more or less dark patches with shaded zones of different forms, the most remarkable of which, projected on a lighter background, shows something like the shape and orientation of the Indian Peninsula.

The immobility of these patches enables us to determine precisely the period of rotation of Mars, which amounts to 24 hours, 23 minutes, and 27 seconds of mean solar time. The plane of the Martian equator is inclined to the ecliptic by about the same amount as the earth's equator. The succession of seasons and days is therefore very similar to our own. We must remember that the Martian year is a little less

than two of our years, that its diameter is a little more than half that of the earth, that its mass is about one-tenth of the earth's mass, and that the planet has two very small moons, discovered by Hall, and called Phobos and Deimos.

There remain the famous "canals." As observed by Schiaparelli and his successors, they constitute on the surface of Mars a network of black lines which are generally straight, and converge towards small dark patches which, for some reason, have been called "lakes." The narrowest of these "canals" are over 12 miles across. Generally they form a larger black patch where they cross, and nearly all the "lakes" of Mars are the junctions of several "canals." Thus, there are seven "canals" converging in the patch which has been called "*Lacus Phœnicis.*" Observe the quotation marks with which we persistently adorn the words "lake" and "canal." These quotation marks are essential as showing that we employ these sacred terms without assigning to them a necessarily objective significance.

Another extraordinary phenomenon announced first of all by Schiaparelli, then by other astronomers, is the "doubling" of the "canals." Some of these at certain moments seem to be doubled into two neighbouring parallel lines.

The number of "canals" observed has been growing, and Schiaparelli's principal successor, the Ameri-

can astronomer Percival Lowell, has brought it to over four hundred.

If the polar caps of Mars are snow and if the "canals" really exist it is certain that the question of their origin is one of great interest. According to W. H. Pickering, they are lines of vegetation, which become more luxuriant when the water from the melting snows reaches them in the spring.

Indeed it is at this season that according to certain observers the "canals" are most visible. Lowell goes further, and supposes that these lines of vegetation develop in this manner because they are irrigated by "canals" artificially dug. The absolute straightness of these lines is against their being considered of natural origin. This implies the existence of life on the planet, and a high degree of intelligent civilisation. The regions away from the "canals" would be deserted, and the inhabitants, in order to make life tolerable, and to grow the necessary produce, would use the melting of the polar snows and direct it carefully along a powerful system of "canals" which they have dug in order to fight the extreme dryness of the Martian climate.

It is possible to discuss the various points of view of this ingenious and attractive hypothesis, which has many followers, even in France. We may discuss its political economy, its psychology, its biology, its agricultural aspects, and what the Americans call

its efficiency. Space does not permit an examination of all this, although there would be very much to say.

Still, we may remark that it would after all not be a sign of a very high intelligence to construct thousands of miles of canals, always in straight lines, and of uniform width, without any regard to the inequalities of the soil, and to variations of fertility. The irregularity of the edge of the polar cap shows that the surface of Mars is far from being flat. The different tints of the Martian patches show that the surface is not uniform. How can we imagine the inhabitants, who are supposed to be intelligent, digging under such conditions their "canals" along absolutely straight lines, and with a perfectly uniform width? On the other hand, there is no economy in taking water to a distance of 3,000 miles from its source, while leaving quite close to the latter vast desert territories without any irrigation. The expense must be considerable.

And if there is any life on Mars, why suppose that the beings who have attained a high degree of civilisation should have any physical resemblance to human beings? The terrestrial animals and the most reasoning (I do not say reasonable) among them, Man, are adapted to the surrounding conditions, as otherwise they would have perished. For instance, our skeleton allows us certain mechanical efforts which depend upon gravitation. Our lungs are adapted to the pressure of our atmosphere, and the quantity of

water on the earth and in the air is an important factor of terrestrial life to which the latter has adapted itself. Now all these essential conditions are relatively different on Mars. Gravitation on its surface is only one-third of what it is on earth. Atmospheric pressure is only a very small fraction of ours. The constitution of the atmosphere must be very different, as also is the intensity of sunlight. Organised life must surely be different from what it is here. Economical and political considerations relating to Mars which one can base upon analogy, as Lowell does, are surely somewhat childish and erroneous.

Finally, I shall limit myself to examine without any theoretical or inductive consideration the question of the "canals of Mars," from the point of view of fact. It is perhaps a point of view which lacks the misty breadth of imagination. But what a solid pedestal does it not, with all its narrowness, offer to our convictions!

Mr. Percival Lowell has made himself in America the enthusiastic apostle of the Martian "canals." That is to say, of their existence as products of art due to a superior civilisation. He has even come to France to preach the crusade, and has recently told us how he was present, at the end of his telescope, at the inauguration on Mars of a gigantic "canal" with locks. He forgot to tell us whether the head of the Martian state, who presided at this planetary

ceremony, was an hereditary sovereign, or was elected by a Congress of the people. But that was evidently his discretion, and was due to his wish not to influence by the weight of celestial authority the political struggles which divide and agitate poor humanity.

It is a point on which we are all in agreement. Whatever may be, not our disdain—we must never disdain that which is agreeable—but our mistrust of the extrapolations of fancy and imagination, if the "canals" of Mars exist in all the detail attributed to them they must be a wonderful work, created by astonishing engineers who are far ahead of ours, although they do not come from our great schools of engineering.

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Granting this point, let us put the little question which arises: Do the Martian "canals" really exist on the planet? Are they not due to some defect in the means of observation of the astronomers who believe in their existence?

Without taking sides, let us investigate the facts. They will give us a reply.

We remark one thing. All those who believe they have observed straight "canal" on Mars, used telescopes of feeble or medium power. The telescope with which Schiaparelli discovered them had an aperture of only nine inches.

Let us say in passing that astronomers obstinately

cling to the inch in expressing the dimensions of their objectives and mirrors. It is a regrettable offence against the majesty of the metric system, but it must sometimes be committed if we do not wish to be "out of it."

Nothing resembling canals is seen on observing Mars in the few telescopes of great power which are at the disposal of the observatories of Europe and America. With these the surface of Mars appears powdered with very numerous small patches whose distribution shows no symmetry. As the telescope becomes less powerful (the power of any telescope or at least its resolving power may be diminished by using diaphragms), these small patches seem to coalesce with each other, and to form chaplets and even regular lines. *These are the "canals"!*

Thus, with the supertelescope of 30-in. aperture of the Lick Observatory in California, which is on the top of a mountain in an exceptionally clear atmosphere, the celebrated astronomer Barnard never saw on Mars the slightest appearance of a geometrical formation resembling the "canals." He announces, on the contrary, that the spots on the Martian surface always appeared to him very irregularly distributed, while on observing with less powerful telescopes he acknowledges having seen straight-line appearances which became clearer and more numerous as the telescope became more feeble! Now the Lick tele-

scope is the instrument with which the same Barnard discovered the fifth satellite of Jupiter, a small star only 30 miles in diameter. This suffices to show the respective values of the observer and his instrument.

The most powerful telescope in the world, more powerful even than the Lick, is that of the Yerkes Observatory near Chicago. Its object-glass is 36 in. in diameter. To some person who, in connection with the sensational declarations of Lowell, asked him what this unique instrument showed on Mars, the eminent Director of the Yerkes Observatory, Mr. Frost, replied by the following telegram, which shows a remarkable mixture of Roman brevity and Anglo-Saxon humour: "*Yerkes telescope too powerful for 'canals'!*" We see that Mr. Lowell has encountered some contradiction from American astronomers. Clearly no one is a prophet in his own country.

If we now pass to the European observatories, and particularly those of France, we arrive at the same conclusions. The most powerful telescope of France is that of the Observatory of Meudon. The astronomers who have examined Mars with this great instrument have seen nothing resembling canals. Among these observations those of M. Antoniadi must be particularly singled out because this astronomer is among those who, having formerly studied Mars with more feeble instruments, had long seen and

indicated in his diagrams a large number of "canals" on the planet.

From all this it takes only common sense to conclude *à priori* that undoubtedly the "canals" of Mars do not exist objectively on the surface of the planet. It is in fact inconceivable and inadmissible that objects revealed by medium telescopes, and seen better as their power diminishes, objects which no longer appear when they are very powerful, should really exist.

But a denial is not a sufficient explanation. Capable observers whose experience and good faith cannot be doubted have independently observed with telescopes of low power the appearances which have been called "canals" on Mars. The geometrical arrangements of these "canals" agreed in the different observations.

How is this possible? How is it that with a feeble telescope one sees things which cannot be seen with a powerful one?

The explanation is very simple. Various savants have contributed to establish it. Notably the much-regretted Charles André, Director of the Lyons Observatory, who was one of our own pioneers of that science of astronomical physics which is now so flourishing in America.

This is it. The particular power which telescopes have of distinguishing detail is called the separating

power. This name is derived from the fact that if we observe in the sky those curious systems called double stars, constituted by two neighbouring suns revolving round each other, the two components are not clearly separated except with powerful telescopes. Otherwise the two points seem joined into one. Now we know—that is to say, we calculate and then corroborate it—that this separating power is the greater the greater the diameter of the objective. The two components of a double star seen clearly separated with a certain objective, are finally confounded if a sufficiently small diaphragm is interposed.

The same phenomenon is seen when two narrow parallel lines are traced on paper. On moving away from them a moment arrives when they appear confused. At a certain distance one does not know how many stripes a colonel or general has on his sleeve, and these stripes seem to form a single golden patch. In the same way, the eye does not distinguish directly the fine pattern of a process photograph which does appear under a magnifying-glass.

Similarly, the small distinct and separate spots on Mars seen in the larger instruments, appear in instruments of smaller power conglomerated, anastomosed, and joined together by lines.

But why are the apparent lines, which are optical illusions, straight and not curved? This is a fact not yet sufficiently explained by physiologists, but

the reality of which has been demonstrated by numerous experiments. For lack of space, I shall only quote one, due to the celebrated American astronomer, Simon Newcomb. Newcomb had drawn on a white disc a series of dark patches, placed irregularly and in such a manner as to obtain an appearance roughly analogous to the image of Mars in a very powerful telescope. Numerous famous astronomers, and particularly Barnard, placed at a distance from this model, so that the separating power of the eye was greatly diminished, and invited to copy it, traced designs on which these separate patches were joined by straight lines. The curious thing is that it was just Barnard, who had never seen any "canal" on Mars, who drew of this model a design most closely resembling Lowell's Martian images.

Finally the Italian astronomer Cerulli showed that with a sufficiently feeble telescope, or one sufficiently stopped down, we may see on the moon itself appearances identical to the so-called "canals" of Mars.

But the apostles of these "canals" did not consider themselves beaten. They have appealed to small photographs of Mars obtained with the telescope, particularly by Lowell, on which are seen straight lines analogous to the "canals."

To this M. Charles André has opposed the strong argument that the optical defects due to insufficient separating power are the same in photography as

they are in eye-sight. The sensitive plate is nothing but a sort of registering retina which faithfully records even the faults of the images received. In confirmation of this point of view, we may cite a curious experiment of Messrs. Lumière, of Lyons, the celebrated makers of photographic plate. If we photograph a certain diatom, *Pleurosigma angulatum*, with two objectives, the second of which has a small separating power, we find that the separate points which cover this diatom, and which are clearly distinct on the photograph given by the first objective, are joined by straight lines on the photograph given by the second.

It happens that Mr. Lowell confesses in his last work that he did not succeed in photographing the "canals" of Mars until he had stopped down his objective considerably, and so diminished its separating power.

Finally, Mr. Hale, the learned astrophysicist of the Mount Wilson Observatory, photographed Mars with the giant telescope of that observatory, a unique instrument with a wonderful mirror 60 in. in diameter. The photographs thus obtained in a perfect atmosphere, and with an instrument of unrivalled separating power, show on Mars a mass of fine detail hitherto unknown. They do not show the least trace of the so-called rectilinear "canals" of Schiaparelli, Lowell, or their French followers.

All this brilliantly confirms the remark of Newcomb: "The numerous speculations put forward on the habitability of Mars are fancies which are not based on any positive fact of observation."

To put it more precisely, we may, I believe, conclude that the famous "canals" of Mars do not exist, or at least that they do not exist on Mars. They are not purely subjective phenomena. They are instrumental appearances, due to the optical defects of medium telescopes, and particularly to their low power of separation.

If Mr. Lowell had not been deceived, when he wrote, "The aspect of Mars indicates a human labour which cannot possibly be doubted" (he was wrong to say human because not all intelligence is necessarily human), it is because this human labour is simply that of Schiaparelli, of Lowell himself, and his imitators. They have seen "canals" in Mars, just as they could have seen stars if they had knocked their eye against the telescope.

It is a pity. It would have been very pleasant to believe in the proof of the existence of this cyclopian network of canals of irrigation, the work of a high superterrestrial civilisation. For the present, unfortunately, we must continue to think that no manifestation of intelligent life is known on any other planet but our own. This does not mean that thinking organisms only exist on the earth. I am even

inclined to be convinced of the contrary. It only means that this phenomenon, if it exists, has hitherto escaped us on account of the clumsiness of our means of observation. It does not belong to science, but to the imagination. Imagination is not always error; it is often truth which cannot be proved, or at all events, is not yet proved.

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So the famous "canals" of Mars are simply optical illusions. What was long considered the evidence of a great civilisation, established on our neighbour in space, does not objectively exist. But what shall we say of those mysterious Hertzian waves which have been captured on earth, and thought to be wireless signals from the Martians? In the absence of the non-existing "canals," are they not the long-expected proof that there is somewhere another inhabited planet?

It was a conversation, or interview, with Marconi, reported with scare headlines by the English newspapers, which brought us the startling news that Hertzian signals of extra-terrestrial origin had been registered.

The compilation and comparative examination of signals by the various Marconi stations has shown on various occasions Hertzian waves which obviously did not come from known radio-telegraphic stations, and which no doubt were from a source far from the

earth, since their intensities were the same at receiving stations separated by thousands of miles.

Well, before assuming that these extra-terrestrial waves are intelligent signals, we must ask if they cannot have been caused by natural phenomena unconnected with any conscious will.

The Hertzian vibrations have indeed been discovered by purely artificial means, but are there not in nature conditions analogous to those complicated ones which, in the laboratory, give rise to waves? To this question nature replies in the affirmative. The Hertzian waves are of electric origin, and are produced by an oscillating spark. Now there are oscillating sparks which are not produced by our engineers: the electric discharges of storms and lightning. Thundering Jupiter had preceded Hertz by a long time, but we did not know it.

Thus science often consists in discovering things which existed from all eternity, I mean before mankind existed, but which our coarse senses did not perceive. It consists, in a word, in prolonging or increasing our sensitiveness, our feeble powers of perception, and so to raise the deceptive veils under which nature hides her nakedness. Science also sometimes consists in creating realities which did not exist, but of which only the possibilities or conditions were present. It is then that knowledge becomes power. Thus, a great number of substances created

by organic chemistry have never existed in nature, and mankind has added them to creation.

For many years, and since the foundation of radio-telegraphy, certain savants, notably Popoff in Russia, Tommasina in Switzerland, and Fenyi in Hungary, registered Hertzian waves emitted by terrestrial storms by means of wireless telegraph apparatus. The electric discharges of our atmosphere are powerful generators of electro-magnetic oscillations.

As these waves can be perceived at a great distance, they allow us to announce the presence of a storm which would otherwise remain unknown. We can even tell whether the storm is approaching or receding, increasing or diminishing. It gives us a real prediction of storms a short time ahead. Warning services have been established on this principle in the United States.

These facts, and others which would be too long to enumerate, led us nineteen years ago to announce to the Academy of Sciences that the sun must necessarily emit, besides its heat rays and luminous rays, a great abundance of intense Hertzian waves.

This results *à priori* from the very nature of these waves. If the luminous waves act upon our retina and other waves do not, it is only due to a sort of physiological accident, as expressed by Henri Poincaré, who also says: "To the physicist the infra-red does not differ more from the red than the red does

from the green, the wave length being greater in each case. That of Hertzian radiations is still greater. It is only a difference of degree."

Other considerations, no longer derived from the experimental or theoretical analogies of physics, but drawn from the facts themselves, those despotic masters of ideas, lead us *irresistibly* to the conclusion that the sun is a gigantic radiator of electric waves, and that these *must* be produced there under the same conditions as those of our laboratories and our atmosphere, except that the scale of the phenomena is infinitely greater.

The atmosphere which surrounds the terrestial crust is strongly electrified and is such that the earth is negatively charged with respect to the air. The electric field of our atmosphere is very powerful. There is a difference of potential exceeding 100 volts per metre of altitude on the average. Very strong electric discharges are produced in the air whenever violent mechanical disturbances, cyclones, certain stormy depressions, or volcanic eruptions, break up the equilibrium of the strata of electrical level. These discharges produce, as we have seen, intense Hertzian waves.

We shall see further on, in studying the sun, that its surface is constituted by photospheric clouds, or " rice grains " animated by movements so rapid that the solar images vary from one minute to another,

and that the most formidable cyclone on earth has only an infinitesimal speed in comparison. Similarly, the lower part of the solar atmosphere is subject to perpetual and violent eruptions, as shown by the spectroscope. All these movements must generate electric discharges similar to those of our storms, but incomparably stronger, and of the nature of powerful Hertzian waves.

Spectrum analysis leads to the same conclusion. It has shown, notably through the beautiful researches of M. Deslandres, that the eruptive protuberances of the solar atmosphere which decorate the black edge of the moon with red flames during total eclipses, are electrically illuminated, and are produced by discharges corresponding to those of terrestrial storms.

Thus we were led to demonstrate that the sun must emit Hertzian waves, and that this emission must be particularly intense in the regions and at times of great perturbation, that is to say, in the region of sun-spots and faculæ—and at the time of maximum of sun-spots.

It seems exceedingly probable that the Hertzian waves of cosmic origin registered at the Marconi stations are just these solar electric waves.

Before attributing these Hertzian signals, received from celestial space, to an imaginary interplanetary conversation, to some friendly telepathic or telegraphic correspondence of our astral neighbours, it

is obviously simpler to look for the cause among ordinary natural phenomena.

It is true that the taste for the marvellous is not entirely satisfied, or at least for those marvels which cradle the eternal infancy of humanity, and which have given us such delicious trifles as *The Arabian Nights*.

To the philosopher only that is marvellous which is also true. The story of the Sleeping Beauty is wonderful. But I find it much more agreeable than surprising. If Louis XIV had been asked what he found the more surprising: that a beautiful girl could really sleep in an enchanted wood for centuries, until a Prince Charming came to wake her up; or that he could speak softly and in a natural tone from Paris to London, what would he have replied? I suppose he would have locked up the prophet of the telephone in the Petites-Maisons, and have made him who announced the other news a Gentleman-in-Waiting. Especially as he had every interest in cultivating the belief that Prince Charmings are possible.

This does not hinder several American professors, whose names I need not mention again, from making renewed efforts to catch the radio-telegrams of our astral neighbours during the next opposition of Mars.

One of them even went up in a balloon as far as 9 miles in order to receive the Martian telegrams more easily. The result was negative. This Professor,

who, in order to catch something at 57,000,000 miles, rises 9 miles into the air at the risk of losing his breath and breaking his neck, reminds me of the hero of some great writer. If I remember rightly, a good old captain who had to teach his men direction-finding by night during manœuvres, got the teacher, who represented science in the company, to show him the Pole-star. Then, after having looked for a moment at the little star twinkling overhead, he shouted: "But they will all sprain their necks. Let the whole company move back fifty paces."

Why do people persist in wishing that elsewhere, even in the nearest suburb of our solar system, there should be beings similar to us, who devour each other and who think, and therefore suffer? Is it not wiser perhaps to consider organised life as a protoplasmic accident, as rare in space as it is in time?

Nothing has yet proved that life exists anywhere but down here. Certain proud spirits will rejoice in this.

In the mute symphony of the golden starry orbs, the cries ascending from the earth are a discord for those whose soul loves an impassive silence. Yet the social instinct in man has always induced him to dream of distant worlds, like ours, where ephemeral conscious beings are born, move about for a short time and are then dissolved.

Such a belief is, indeed, connected more closely

than seems likely at first with politics and history. The face of the world might have been different if Aristotle, instead of imagining the stars made of a divine substance, essentially different from the earth, had believed them to be inhabited. He would certainly have taught this opinion to his restless pupil Alexander, and the despair of this young hero in imagining the existence of nations escaping from his domination, would have perhaps made him renounce his plan of conquering this little earth.

I am well aware that most people, and even many who profess science, are less jealous of their place in the universe than of their rank on the small steps of the human ant-heap. Yet, for people capable of reflection—and there are some, whatever the pessimists may say—the belief in the habitability of the planets is an excellent antidote to the two most terrible diseases that exist: ambition and restlessness.

Do not be surprised at my discussing the astral plurality of life with aid of arguments so foreign to positive science. There are, as we have seen, no better arguments. Our brothers of other worlds are charming and consoling myths, which we love to imagine in hours of despair, and they may either exist or not, according to our mood, being beyond the prosaic reach of observation. Nothing better has yet been found in favour of the plurality of worlds

than the reasoning by analogy, which was so prettily developed long ago by the good M. de Fontenelle. And when I am told that stupidity, in the comical form assumed in man, is a thing which ought to be generally spread in the universe, let us acknowledge with him that, pending a more geometrical demonstration, we are almost convinced.

It is amusing to remember that prize of 100,000 francs bequeathed to the Academy of Sciences by an excellent lady for the first person to communicate with a planet —other than Mars. The donor thought that Mars would be too easy! She had at least the wisdom not to require that the interest on this capital should accumulate. This is very fortunate, since in all probability this sum, placed at compound interest, would, before having been awarded, have absorbed the whole capital of the earth, thus provoking wars and the most terrible economic crises. Let anyone say after this that astronomical questions are of no practical importance!

Since the belief in the plurality of inhabited worlds is not yet either confirmed or refuted by science, I consider it proper and useful to support it. It offers a safeguard against anthropocentric views. We must admit that if nowhere else in the universe there were either thought or suffering, if nowhere else there were any brains conceiving ideals, our little globe would be in truth, in spite of the mediocrity of its mass and

its position, the capital of infinite space. And knowing this, men would perhaps become conceited, which would be inconceivable.

As regards entering into relations with the hypothetical inhabitants of other planets, this is a problem which will not be solved so quickly.

Problems more pressing than inter-planetary telegraphy face those who desire long-distance conversation. Let them try to communicate with the thoughts of our elder brothers, the animals, from which a deep gulf separates us! Let them try to render accessible, one to the other, those dark and hermetic urns which are called two human souls!

And does not mineral matter present us with problems which are as accessible, and no less interesting, than those perishable and charming molecular edifices which we call human beings?

This is a question I shall not try to solve, since it has more faces than a hexa-octohedron.

CHAPTER III

THE SUN AND ITS WONDERFUL INFLUENCES

Spectrum analysis and the solar atmosphere—The photosphere—The sun-spots and their rhythm—Temperature and radiation of the sun—The spectro-heliograph—The magnetic field of sun-spots—Action of the sun upon terrestrial magnets—Electric radiations—Radium and the agony of Helios.

THE study of that small star which classic poets call the "day-star" has made giant strides of late. If we think that only about 2,000 years ago—an atom of eternity—some Athenian made a great scandal and was even accused of impiety for having dared to suggest that the sun was perhaps larger than the Peloponnesus; when we remember that quite close to our time, only a century ago; Herschell believed the sun inhabited and that even yesterday or nearly so Arago considered it habitable; if we compare this with our present knowledge, we cannot but admire the triumphal march of science through this forest but recently cleared. All terrestrial life depends on the sun, but its importance is only due to its proximity. It is quite close to us, only 93,000,000 miles away, which is very small as sidereal spaces go. This permits us to study it more exactly than other stars. In glancing through the doors recently

opened on the mystery by solar physicists, those modern priests of the sungod, we shall rather better estimate our ignorance concerning the vast universe, peopled by the millions of inaccessible suns of the Milky Way.

Our sun is indeed one of the humblest and most modest of the stars. Aldebaran, the red eye of the Bull, one of the most beautiful stars of the evening in spring (but not the most beautiful) sends us an amount of light which is 90,000,000 times less than the light which we receive from the sun. Yet if the sun were placed at the distance of Aldebaran it would only be a star of the fifth magnitude, hardly visible to the naked eye and forty-five times less brilliant than Aldebaran. But there are others, Rigel, Canopus, and Deneb, which are immensely farther away than Aldebaran and still brighter than the latter. Beside these our sun would be a very pitiable rushlight.

Let us not, however, despise it. Let us rather bless the providential chance which enables us to nestle under the warm wing of its vivifying rays. Without the sun we should not know there are yet brighter stars. Until we discover in some other stellar system —it will not be to-morrow—other thinking beings, however badly they think, we shall retain the right to consider our small system as the capital of the universe and the sun as the lighthouse of the world.

Thus our ignorance remains the last defence of anthropocentric pride.

The older methods of observation, the astronomical telescope and celestial mechanics, have enabled us to know the distance of the sun, its volume, 1,206,000 times that of the earth, its mean density less than a quarter that of our globe, and its mass 332,000 times that of the earth, and which produces on its surface a force of gravitation amounting to 27 times our own weight. On the other hand, it is only through the new methods of astrophysics and especially through spectroscopy that we have gained a fairly accurate knowledge of the physical constitution of the sun. These methods have unravelled the physiology of this immense organism of which formerly we only knew the anatomy.

We know that the light of the sun falling upon a fine slit and spread out in a fine spectroscope, shows itself as a continuous luminous band displaying the various colours of the rainbow, but interrupted by a multitude of fine black lines whose position remains sensibly constant. They correspond to the various chemical elements found in the atmosphere of the sun, close to the blinding disc from which we get the light, and which on that account is called the photosphere. Until a few years ago nobody had succeeded in producing an artificial spectrum corresponding to that of the sun except by placing incandescent gases

in front of a luminous solid or liquid source hotter than themselves, which was rendered incandescent by heat and also furnished a continuous spectrum. From this it had been concluded that the luminous clouds in constant motion which form the photosphere and whose detail appears on the wonderful photographs of the Meudon Observatory were composed of solid or liquid particles.

But there is one curious circumstance: the temperature of the photosphere has been, as we shall see, found to be greatly superior to the boiling point of all the known chemical elements. How then could this photospheric matter not be in a state of vapour? and if it was, how explain its continuous spectrum? Vain efforts were made to get out of this contradiction. Recent researches offer an escape. They have shown that the bright spectrum rays of the gases which are fine and sharp at low pressures, widen out as the pressure increases until they join up and give a continuous spectrum. The modern tendency is therefore to think that the sun, including its photosphere, is entirely gaseous.

We do not know much about what goes on under the photosphere. It hides from us the interior of the sun, just as the clouds hide from us the surface of Venus or Saturn. And why be surprised at our own ignorance if we know nothing by positive observation concerning the interior of the earth more than

about a mile under our feet? One thing is certain in any case: there must be on the sun enormous temperatures and pressures amounting to millions of atmospheres. What becomes of the gases compressed to that extent? We cannot imagine.

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It is the photosphere which sends us the greater part of the heat and light which we receive from the sun. Its rays are absorbed to some extent by the upper layer of the solar atmosphere and the consequence of this has been found to be that the edge of the sun appears less bright and also more reddish than the centre. Our atmosphere behaves in the same manner; it absorbs the sun's rays, but to an unequal extent, and more at the violet end of the spectrum than at the red end. This is why the setting sun seems to us less luminous and more reddish than the midday sun.

Considered altogether, the photosphere sends us amounts of radiant energy the precise determination of which has long been one of the fundamental operations of astrophysics. It has been found that each hemisphere of the sun sends as much light into space as 9,000 quadrillion candles. The miserable rushlight which we have just despised is therefore bright enough after all.

In order to express the thermal energy of solar radiation including its luminous rays, astrophysicists

define a certain quantity which they call the "solar constant." It is the quantity of heat received vertically from the sun for one minute by each square centimetre of the earth, adding that which is absorbed by the passage through our atmosphere. This quantity has been wrongly named, for what it measures is anything but constant; but astronomers have no doubt plenty to do without purifying their language, and everybody knows what is meant.

Now this solar constant, to call it by its ordinary name, is found, according to the most recent experiments, particularly that of the American Observatory of the Smithsonian Institution, to be very nearly two small calories. This means that the solar radiation would suffice to raise a uniform layer of water one centimetre thick, surrounding the sun like an immense globe at the distance of the earth, by 2° in one minute, or from zero to 100° in 50 minutes. From this datum it has been proposed to deduce the temperature of the sun, or rather of the radiating layer of the photosphere. In order to do this it suffices to apply the law discovered by the physicist Stefan, which links the temperature of a source to the thermal energy it radiates. According to this law the energy radiated is proportional to the fourth power of the absolute temperature. This method has led to a figure a little above 5,000°. Numbers of the same order of magnitude have been reached by very different

methods and notably by studying the ratio of intensity of the different regions of the visible solar spectrum.

The "effective temperature" of the sun is therefore about 5,000°. Since the various layers of its globe are certainly at very different temperatures, the outer layers being colder than the inner ones, the above conclusion means this: the radiation which we receive from the sun is in quantity and quality nearly identical with that which would be sent to us by a star of the same dimensions as the sun, situated at the same distance and every part of which would have a temperature of about 5,000° and a power of emission equal to unity, as is the case, for instance, in lampblack. As we see, the idea of the temperature of the sun is much more complex than it is ordinarily supposed to be. We cannot imagine it otherwise when we think how many different and variable data the meteorological notion of the mean temperature of the surface of the earth represents.

Before the physical laws of radiation were known the most fantastic ideas were held concerning the temperature of the sun. Herschell and many others thought the sun was cold and dark, covered with mountains and valleys and with a luxuriant vegetation. It is true that he announced these astronomico-bucolic theories in the eighteenth century when there was a fashion in favour of shepherds, a fashion which

even spread to royal courts. Why should these stars escape from that fashion, especially the star which had the particular honour of being a symbol of the greatest Louis of all ?

When the Christopher Columbuses of spectrum analysis, Kirchhoff and Bunsen, had shown that the composition of the sun's light was only compatible with a state of high incandescence, opinion ran to the other extreme. Father Secchi particularly, who has indeed contributed to astrophysics certain imperishable works, attributed to the sun a temperature of 10,000,000°. M. Violle, who was the first to put a little order into this uncertainty, defined the notion of effective temperature and showed that that of the sun could not surpass a few thousand degrees. He told me that in talking to Secchi on the question one day, he proposed to compromise and to adopt an intermediate number between their respective figures ; but Secchi would have none of this, and stuck to his millions of degrees with smiling pertinacity. The modern work of physicists on radiation, which alone could have convinced him, had not yet been born.

The surface of the photosphere is not all homogeneous. It consists of granulations separated by darker patches in a state of extraordinary motion which displaces masses larger than France with speeds of several miles per second. In this sea of incandescent clouds there are peaks and depressions.

The peaks are the so-called *faculæ*, which project from the surface of the photosphere like the pillar of light which guided the Israelites. They appear in the telescope or on photographs brighter than the general average of the photosphere, probably because their height enables their light to reach us with less absorption from the solar atmosphere. The depressions or holes seen in the photosphere are the sun-spots.

When, after the invention of the telescope about 1610, Fabricius, Scheiner and Galileo in turn discovered them, there was great astonishment. It was the last blow given to the old mystical astronomy of the Middle Ages which, with its complicated system of spheres of celestial crystal, had conceived the stars to be spotless and in some way immaterial.

In general the sun-spots have an aspect of a central nucleus very dark in comparison with the rest of the disc and surrounded by a lighter penumbra. One is reminded of a funnel thrown into the photosphere and terminating in a deep hole. Some of them are as large as 1/20th of the diameter of the sun, that is to say, about five times the diameter of the earth. While observing them one sees that they are slowly moving. Thus it was discovered for the first time that the sun is not immovable but rotates about an axis slightly inclined to the ecliptic and in the same direction as the rotation of the earth and the revolu-

tion of the planets about the sun. In this manner and with the aid of observations on the faculæ some curious laws, governing the rotation of the sun, were discovered. That rotation does not take place *en bloc* like that of a rigid and coherent body, but it takes about 25 days at the equator and a little more in other parts. At a distance mid-way between the poles and the equator the photosphere takes 27½ days to complete a rotation. This is very strange. We might have expected to see the equator turning more slowly than the rest, since, for the same angular velocity, its linear speed would be greater. We shall not enter into the discussion of the innumerable theories put forward to explain these facts. They are almost too complicated not to touch the truth in some point and too ingenious to be perfect. Besides, it is only the facts which matter.

It is particularly spectrum analysis, that unexpected auxiliary of the astronomy of position, which has furnished us with accurate and interesting revelations on the movements of the sun. This was rendered possible by the application of the Doppler-Fizeau principle, or the principle of radial velocities. This enormously fertile method has thrown unexpected floods of light into nearly every domain of astronomy. Let us briefly recall of what it consists.

We have all noticed when the whistling engine of

an express flies through a railway station at top speed the sound of the whistle, which seemed very high while the express was approaching, suddenly falls as the engine passes through the station and recedes in the distance. It would have had an intermediate pitch if the train, while continuing to whistle, had stopped in the station.

The reason is simple. The pitch of the sound depends upon the length of the waves emitted by the whistle. Now this wave-length is diminished by the speed of the locomotive when it approaches. It is increased, on the other hand, when it recedes. In fact the engine, while approaching us, pursues in some way the sound waves, compresses them and presses them towards us. When, on the other hand, the locomotive passes from us in a direction opposed to the waves emitted towards us it tends to extend and to lengthen them. The sound is therefore made sharper in the first case and flatter in the second.

The same thing applies to light-waves. The lines of a chemical element are displaced towards one end of the spectrum or the other by a small quantity which indicates the speed of the source towards us or away from us—that is to say, its radial velocity. If the source moves away from us the wave-length of the lines of the spectrum is increased and the lines are displaced towards the red end of the spectrum.

They are displaced towards the violet end in the opposite case, and these displacements are easily measured. In the case of the solar rotation, it is even much simpler. It is sufficient to receive on the slit of the same spectroscope the images of the two opposite edges of the sun situated at the extremities of the equator or of a parallel of latitude whose speed of rotation we wish to measure. Each line appears double because one of the edges is approaching us while the other is receding. The amount of this doubling enables us to know the difference in the linear velocities of the two edges whence we may easily deduce the speed of rotation. Yet there are certain lines of the spectrum which do not appear double. They are the lines due to the absorption of the solar rays by our atmosphere and particularly by oxygen. Janssen has called them "telluric lines," and that is indeed a method of discovering them.

By this procedure astronomers have confirmed and extended as far as the pole the law of decrease of the solar rotation which the observation of sun-spots only allowed us to know for certain latitudes which they frequented. While the sidereal rotation takes place in a little less than 25 days at the equator, it takes 26·3 days at the latitude of 30°; 31 days at 62° and 35·3 days at latitude of 80°. These enormous divergences are surprising. They are, however,

constantly in evidence whatever may be the lines of the spectrum which we examine.

We sometimes find systematic differences, the rays of one chemical element giving greater linear velocity on the same parallel than those of another. This is due to the fact that the first element is found in a layer of the atmosphere which is higher above the photosphere than the other element. This gives a convenient means of finding the altitude of the strata which contain the various chemical elements. In particular and quite recently it has been found by this method that there are enormous masses of gaseous calcium high above those strata which furnish the solar hydrogen lines and that in spite of the much greater lightness of the latter gas.

The sun-spots have a lower temperature than the photosphere. This is evident from the researches made by Lockyer and more recently by Hale, Adams, and King, who compared the spectra of elements vapourised in the arc and the electric furnace with those of the photosphere and the sun-spots. This also follows from the fact that they show in the spectroscope spectrum bands which are not seen in the photosphere. These are due, as has been found lately, to the presence in the spots of various metallic oxides and hydrides, particularly those of titanium, magnesium, and calcium. It is well known that at a high temperature the chemical compounds tend to

dissociate and that they cannot exist at the temperature of the electric arc. The abundance of these bands in the spectrum of the sun-spots enables us to assign to the latter a temperature of about 3,500°.

In the history of sun-spots the best established fact is their curious periodicity. About every 11 years—on an average 11·1 years—they are nearly absent from the surface of the disc. Then for three or four years their number and their total extent increase gradually to a maximum; they then remain practically stationary for some time, afterwards diminishing for about six or seven years until they disappear and recommence. The last maximum of sun-spots was in 1917 and the preceding minimum was in 1913.

Untold efforts have been made to find the cause of this strange phenomenon, which, like the gigantic respiration of some internal monster, periodically tears up the surface of the sun, subsequently allowing it to recover only to repeat the same process. Some astronomers have blamed the combined attraction of the larger planets on the solar nucleus and many other things. None of these attempts have been successful. We are indeed in the most complete ignorance of the causes which make our sun not a fixed star but a variable star, corresponding to so many others which the photometer reveals in the depths of the heavens. This is all the more regrettable since all the other solar phenomena recently discovered in

its atmosphere, particularly its curious magnetism, are, like many terrestrial phenomena, closely dependent upon this eleven-year period of solar activity.

It results at least from the discoveries of which I shall have to say more presently, that if there is nothing new under the sun, there are at least many new things on the sun itself.

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The fable of the blind man and the lame man gives a good representation of the parts played in science by theory and experiment respectively. Neither can do without the other any more than the two crippled heroes of Florian. Experiment, if not blind, is at least very near-sighted and knows only that which it can touch with the finger. Its range does not exceed the length of its nose, and it would be marking time on the same spot without the help of theory, of the clear eye which sees obstacles from afar and also the mirage on the horizon. But theory in its turn would be nothing if it were not hoisted on the strong shoulders of experiment. Without experiment it would never be able to distinguish reality from illusion in the appearances seen from a distance. Unable to advance by itself on the solid ground of reality, condemned always to pass its eyes round the immovable circle of the same deceptive panorama, it would remain rooted to the same spot and degenerate into nonsense.

It is thus that a collaboration, stormy sometimes, of experiment which touches and theory which predicts, of realities and systems, fact and hypothesis, have hobbled along to construct the edifice of contemporary science which is still incomplete, but never probably has this collaboration of the brain which guides and the hand which feels been so complete and fruitful as when it found in the sun's atmosphere all those astonishing things which have been discovered there during the last few years.

The existence of a vast absorbing atmosphere round the sun was probable *à priori* by every astronomical analogy. It is experimentally demonstrated by the diminution of the brightness of the sun's disc from the centre to the edge and by the black spectrum lines discovered by Fraunhofer. The latter show that there is round the photosphere a layer of relatively cool gases, whose chemical nature is indicated by these lines. But in reality it is the total eclipses of the sun which first made us aware of this atmosphere. At ordinary times it is quite invisible to us for the same reasons as those which prevent us seeing the stars in the daytime; the brightness of the sun's disc itself and the light diffused by our blue sky. Daylight has therefore long been an obstacle to our astronomical progress, a curtain interposed between the stars and ourselves.

The eclipses of the sun which at rare intervals tear

aside this curtain have shown round the disc covered by the black curve of the moon an immense luminous glory with shafts of light extending millions of miles. It has several divisions; first there is close to the sun a thin ring of a bright pink or ruby colour which is called the chromosphere, from which slender tentacles arise, also of a pink colour, called protuberances. These are sometimes several hundred thousand miles long. We see them in a state of agitation and constant change even during the short duration of an eclipse and their speed is shown by calculation to be quite fantastic, surpassing as it often does 60,000 miles a second. Around the chromosphere and its red protuberances there extends the coronal atmosphere, the enormous greenish crown which constitutes the external atmosphere of the sun.

The study of these various layers by spectrum analysis carried on for half a century during eclipses has proved that the chromosphere and the protuberances are chiefly composed of incandescent hydrogen, and that the green light of the corona is due to a gas which has not yet been identified with any of those known on the earth. It has been called *coronium.*

The spectroscope, that unrivalled instrument of marvellous knowledge, furnished at every new eclipse such a rich harvest of discoveries, while the expeditions organised for every eclipse were so costly and uncertain, since a single cloud could render them

useless, that it appeared desirable to discover methods of showing without eclipses what these capricious and fugitive phenomena had revealed.

Between 1868 and 1906, in 38 years, the number of total eclipses of the sun was 24, with an average duration of 3 minutes and 6 seconds. An astronomer who had organised expeditions to every part of the earth where they were visible would therefore not have seen the solar atmosphere for more than an hour and a half in all. That is very little.

The first step to remedy this situation was taken by Janssen and Lockyer in discovering their celebrated method, now universally employed, to see the protuberances in full daylight. Since then, so far as the chromosphere and its protuberances are concerned, the observation of total eclipses has been almost superfluous. On the other hand, every effort made hitherto to observe the corona apart from eclipses has failed completely. Hence our ignorance concerning the exact nature of this "glory" which sometimes surrounds the superposed faces of the sun and moon.

Yet it has been proved that the corona is composed of extremely rarefied gases which hold very fine dust in suspension, and that it is so light that in spite of its enormous thickness it is transparent to the light of the stars.

If the observation of the corona without eclipses

is still impossible, astrophysicists have carried out a wonderful work in giving us in the spectro-heliograph a means of continually observing phenomena which the eclipses themselves did not show, hidden as they were behind the opaque disc of the moon. I speak of the various layers of the solar atmosphere, not only at the edge of the sun's disc but over its whole surface.

The spectro-heliograph is the common and independent work of two astronomers, one of them a Frenchman, Deslandres, and the other an American, Hale. In spite of its somewhat uncouth name the instrument is, like all really beautiful inventions, founded upon an idea which is both simple and ingenious. I cannot resist the desire to point out briefly in what it consists, at the risk of appearing for some moments rather too technical. We can hardly take a true and complete pleasure in the harmonious structures of science if we have no idea of the mechanisms which have laid the heavy foundation-stones. If science teaches us the how and not the why of things it is of interest to know how this "how" is discovered.

Let us imagine having a fairly large image of the sun at the focus of a telescope and placing the slit of a powerful spectroscope along a diameter of that image, say along the equator. Then we can have at the end of the instrument a complete spectrum of

the solar equator. Let us suppose that we pick out from this spectrum a particular line such as the pink line of hydrogen and then all the rest of the spectrum is hidden by a screen with a fine slit which coincides with that line. Now if we place a photographic plate behind that screen we shall have on that plate a line traversing the equator of the sun, a line whose thickness and intensity will not be the same from one end to the other. They depend in fact upon the distribution along the equator of the masses of hydrogen which give rise to that line. Let us now imagine that while all the rest is immovable, the image of the sun is displaced so that it is traversed entirely and successively by the slit. If at the other end of the apparatus a simultaneous corresponding movement is given to the photographic plate it is clear that we shall receive on that plate a representation of the sun due entirely to its atmospheric hydrogen.

Thus, by isolating one or other of the lines of the spectrum we can obtain an image of the solar atmosphere due exclusively to a particular element contained in that atmosphere or rather to a particular line of that element.

And there is much more. Thanks to the spectroheliograph we have succeeded in finding the distribution in height of a given chemical element, its distribution in various layers of the solar atmosphere

projected upon the disc. That is a wonderful result. Here also the physics of the sun is ahead of that of our globe, since we have no means of determining by a simple optical operation the composition of the various layers of our atmosphere in a vertical line.

It has now been proved that most of the 20,000 black lines found in the solar spectrum are entirely due to the absorption of a thin atmospheric layer in immediate contact with the photosphere. According to the ideas of Kirchhoff it is this absorption which has the effect of inverting the bright lines emitted by that gaseous layer itself and converting them into black lines. The existence of this reversing layer has been recently confirmed by photographing the spectrum during eclipses. Just in contact with the photosphere this spectrum shows for a brief moment—hence the name "flash spectrum"—in the form of bright lines all those which are black in the ordinary solar spectrum. This is a brilliant expansion of the idea of Kirchhoff.

Generally speaking, the heaviest chemical elements are only found in the lower layer of the solar atmosphere. Yet there are remarkable exceptions, and I have already said that clouds of calcium vapour are found far above the altitudes where hydrogen is abundant.

The speeds of these gaseous masses are sometimes excessively high. The cloud of hydrogen vapour

has recently been observed to be attracted or aspirated suddenly in the direction of a sun-spot with a speed of 240,000 miles per hour (the distance between earth and moon). Such displacements, as well as the characteristic curvature of the protuberances, have long convinced theoretical astronomers that the sun is the seat of powerful magnetic and electric phenomena. The very existence of the light of the solar atmosphere proves it, for we know that gases can never be rendered luminous by heat alone and without electrical excitation. These conclusions were as yet unconfirmed by experiment, but that confirmation has been furnished by a magnificent discovery directly resulting from researches with the spectro-heliograph and which we must now proceed to explain.

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Some time ago Mr. Hale noticed that on some of the spectro-heliograms obtained with hydrogen lines gas showed itself over the sun-spots in the shape of tracts irregularly curved towards them, with the appearance of having been influenced by a violent cyclonic movement having its centre in the spot itself.

A closer study shows that this movement of incandescent hydrogen is real. We can indeed sometimes perceive masses of gas violently sucked in towards the centre of the spot. That observation was very interesting in itself since it showed a similarity between the solar atmosphere above the sun-

spots and the cyclones and tornadoes of our own atmosphere. There is nothing surprising in this. But it is from this simple fact of observation that Mr. Hale, by a close chain of combined reasoning and experiment, has arrived at one of the most beautiful and suggestive discoveries of modern astronomy: that of the magnetism of sun-spots and the magnetic field of the whole sun. And this is how it came about.

If, says Mr. Hale, there is a whirlpool of matter in a sun-spot, and if it is electrified, it must produce an electric current as well as a magnetic field. Now matter is most probably electrified on the outskirts of the photosphere.

Indeed, as we have shown, the luminosity of the gases of the coronal sphere is certainly of electrical origin. On the other hand, our terrestrial atmosphere is electrified, and we know that the movement which produces storms also produces those intense electric discharges which we call lightning. These same phenomena, but in a higher degree, must exist on the sun. We know that the sun's light acting on the particles of our atmosphere ionises them—that is, dissociates them into smaller charged particles, some of them charged with negative electricity and others with positive. *A fortiori*, that light could not act otherwise in the sun's atmosphere, where it is millions of times more intense. In fact, we have discovered during the last few years that incandescent bodies

emit large quantities of negative electrons. The filament of an electric bulb may in this manner produce a current of several amperes per square centimetre of its surface. The solar photosphere, which is in a much higher state of incandescence, must behave similarly.

We can therefore not escape from the conclusion that matter in movement in the solar atmosphere must be strongly charged with electricity.

If that is so, then this electrified matter in motion must produce the same effects as an electric current circulating in a wire. The American physicist, Rowland, showed at one time, in a celebrated experiment, that a body charged with statical electricity and moving very rapidly corresponds to a dynamical electric current. In particular, it has, like the latter, the property of deflecting magnets in its vicinity, and we know from the classical experiments of Oersted and Ampère that the sense of this deflection is governed by a simple rule and takes place in such a manner that the magnet tends to place itself across the electric current. In other words, electrified bodies in movement produce a magnetic field in their neighbourhood. It follows that the electrified gases whirling above the sun-spots must act like the giant coil of an electro-magnet and must produce a magnetic field whose axis is sensibly perpendicular to the sun.

All this is well and good, but it yet remained to prove it, and this is what Mr. Hale did, by utilising the Zeeman phenomenon by very ingenious means, which it must be confessed were only made available by the unique organisation and the considerable budgets of American astronomy.

The Zeeman phenomenon, named after the Dutch physicist who discovered it on the admirably prophetic suggestion of Lorentz, is an effect produced by magnets and more generally by all magnetic fields.

According to recent discoveries, light is caused by the very rapid displacements of those minute planets charged with electricity which are called electrons, and which form that miniature solar system which we know as the atom.

A spectrum line of a given gas corresponds to a particular frequency of vibration of the ether, and that is produced by the speed of the electrons revolving round the centre of the atom. Let us consider, for example, those electrons which in hydrogen produce a given spectrum line. If we let a powerful magnet act upon that gas we can divide those electrons into three classes: those which at the time of the experiment are moving in such a way that their movement is opposed by the magnet, those whose movement is accelerated by the magnet, and lastly those of intermediate orientation upon whose speed the magnet has no influence. It is clear that instead

of a single line, these electrons will give three spectrum lines, the central one of which will coincide with the single original line. Further, theory shows that the two extreme lines have the property of being polarised in opposite directions. The phenomenon discovered by Zeeman has shown that, in accordance with the elementary explanation just given, and which is still rather incomplete, such effects are actually produced.

Mr. Hale therefore undertook to find whether the solar spectrum in the neighbourhood of the sun-spots showed the Zeeman effect. For this purpose he investigated certain spectrum lines on the sun-spots which had already been found quite unaccountably broadened or even doubled in comparison with the normal spectrum lines. Success crowned his long series of ingenious efforts. Having thus revealed the existence of the Zeeman phenomenon in the sun-spots, Mr. Hale concluded that these constituted strong magnetic fields whose intensity sometimes reaches 3,000 units—that is to say, more than 6,000 times the magnetic force which, on the earth's surface, directs the magnetic needle northwards. Mr. Hale also proved that the magnetic polarity of the spots depends upon the sense in which they revolve, and that often two spots placed symmetrically north and south of the solar equator have opposite magnetisms. He finally showed by analogous methods that, apart from the local magnetic fields of the sun-spots, the

whole sun is a magnet like the earth itself. The north and south magnetic poles point in the same direction as on our globe, and are but slightly removed from the poles of rotation. The magnetic axis of the sun is inclined about 6° to its axis of rotation.

Finally, a subsequent discovery by the German physicist Stark has brought to these studies of solar physics a new element of interest and hope. It has revealed the fact that these spectrum lines can not only show the existence of magnetic fields, but also, by an effect corresponding to the Zeeman effect, though different in its action, the existence of electric fields which act upon the sources of light.

It is too early as yet to gauge the consequences in astrophysics due to Stark's phenomenon. Certain astronomers regard the new complication which it is about to introduce in the study of solar optics with some anxiety. They are afraid of soon being unable to find their way among the multiple elements which influence spectrum lines. To my mind they are wrong, and it is like complaining that the bride is too beautiful. The greater the progress of science, the more complicated will be the fugitive appearances she shows to us. If this had only the advantage of making us more modest in our pretensions and less self-satisfied in our systems, that would all be to the good. But there are many other attractions, if only the attraction of that which is novel and unheard-of.

In any case, henceforward there will be a rich harvest of discoveries in connection with the atmosphere of our little sun, and it is not in vain that astronomers have gradually lifted the misty veil behind which its disc of liquid gold floats.

Sometimes, and especially in certain years, vast displays of aurora borealis appear nearly all over our hemisphere and extend even to the low latitudes where one is unaccustomed to see those golden draperies floating in the heavens. During those times sun-spots are always seen, and navigators find that their magnetic compasses are disturbed by an unusual agitation. At the same time the surface of the earth is traversed by abnormal electric currents, by those "telluric" currents which violently disturb the transmission of messages in the telegraphic cables.

What relation is there between the sun-spot which at a distance of 93,000,000 miles from the earth tears up the sun's shining photosphere and those inconveniences which are encountered by the most matter-of-fact of our administrators in the transmission of his telegrams? What telepathy unites those very distant things with the magnetic needle which on the bridges of our liners marks out the ocean paths?

That is what we must discuss now.

In a given place the magnetic needle when freely suspended takes approximately a north and south direction. I say approximately because generally

it is deflected slightly towards the east or west by an angle which is called declination. It also points its nose towards the ground, at least in our hemisphere, and makes an angle with the horizon which is called the dip, or inclination. These two angles, together with the variable force which keeps the needle in the magnetic meridian, constitute the three elements of terrestrial magnetism at the spot in question.

These elements vary considerably from one place to another, and in the same place from one year to another.

Thus, at Paris, towards the year 1580, the declination was towards the east and amounted to 9°. From this date onwards the needle turned constantly from year to year a little more towards the west until about 1800. It was then 22° of western declination. Since then it has slowly returned to the east and at the present time it is only about 13° west of the geographical meridian. At the present moment it is about 16° in Brittany and 10° among the Maritime Alps. This shows that it changes not only in time but also in space.

Besides their secular variation, which is far from being explained, the magnetic elements in every place undergo much more rapid fluctuations, so-called short-period variations which are of great interest on account of the strange glimpses which they give us into cosmic physics. They will bring us to the very heart of our subject.

But before penetrating into this curious labyrinth I wish to reassure with a word those persons who by a scruple which may not be very exalted and yet is worthy of respect—scruples are always worthy of respect—ask in connection with every new thing what is the use of it.

The direction of the magnetic needle is of capital importance for navigation. It is thanks to the magnetic compass that Christopher Columbus was able to launch himself on the limitless ocean. It is true that in his time the magnetic elements were imperfectly known. Columbus was much surprised when he noticed, on September 13, 1492, that the needle of his compass, instead of pointing to the Pole-star, deviated from it to the left by 6°. On the following day it was found, after going further west, that the deviation had increased. To his frightened sailors, who thought that the natural laws were upset, and that the magnetic compass was about to lose its mysterious power, Columbus had to impart a flood of reassuring words. He succeeded in calming them by explaining—which, however, is not correct—that the needle turned round the pole like the stars of the firmament.

To-day the mariners and explorers cannot do without compasses and magnetic charts. Even surveyors and practical geometers find them as indispensable as household utensils. Aerial naviga-

tion finds in them a valuable help in its audacious enterprises.

Now all this is useful for some things, and indeed for many things. It gives us what Baudelaire with a somewhat bitter contempt calls "ustensiles." I may even add, paying a rare tribute to utilitarians, that on the other hand navigators have enriched our store of scientific data, still too sparsely distributed, on terrestrial magnetism.

Therefore, even in the eyes of those people of whom Henri Poincaré spoke with a smiling disdain, "whose object in life is to make money," terrestrial magnetism is of great importance. Our knowledge concerning it has a perceptible influence upon the dividends of any concern depending on navigation—that is to say, the majority of human enterprises.

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And now that we have given those hostages to utilitarianism we can with a light heart return to those mysterious regions where magnetic phenomena are nothing more than alluring problems. There we find a pure joy apart from the prose of life which brings us gradually over a thousand enchantments to those summits of pure beauty which our efforts will always approach but never reach: the why and how of nature.

In observing with delicate instruments the magnetic needle, we find that at a given place and in normal

times it undergoes a slight daily displacement. Every day between 8 a.m. and 2 p.m. the needle moves slowly towards the east, subsequently returning to the west and resuming its first direction, after a slight deviation during the night. It recommences the next morning. The amplitude of this diurnal deviation is feeble. The angle between the two extreme positions is only a few minutes of arc, a small fraction of a degree. But the curious thing is that the important part of the variation is produced at every place during the hours when the sun is above the horizon, and in such a manner that the needle seems to follow the direction of the sun.

This shows clearly that the intensity of solar radiation counts a great deal in this daily variation of the compass-needle. Moreover, this variation is much greater in summer than in winter. This implies that in the southern hemisphere it is feebler in July than in December.

At Nice, for instance, the declination of the needle oscillates by fifteen minutes of arc in June and only five minutes in December. The epochs are reversed in the case of a southern station. The other two magnetic elements show analogous variations. On the other hand—and this completes our demonstration—the amplitude of the daily variation, reckoned by the force which it represents in each locality, is greatest in the equatorial regions of the earth, just

where the solar radiation is strongest. It diminishes as it approaches the poles, where sunlight also diminishes.

Even more cogent facts, if that is possible, have come to establish definitely that the daily variation of the magnetic elements closely depends upon the sun.

We have known for 150 years that the sun-spots have a regular periodicity of about 11 years. It is a sort of monstrous respiration with a slow rhythm which periodically opens and closes the radiant surface of the disc.

Now the daily variation of the magnetic elements shows a cycle which is absolutely parallel to that of the sun-spots. In every part of the earth the declination, like all the other magnetic elements, shows daily variations which are the greater the larger the number of sun-spots. In the years of maximum of the latter, the amplitude of the daily variations is about $1\frac{1}{2}$ times what it is during the years of minimum sun-spots. The phenomena as they go on year by year show exactly parallel fluctuations which allow of no doubt that they are cause and effect. All these facts show that a mysterious sympathy links those perturbations which agitate the sun's surface 93,000,000 miles away with the shivers of our little compasses in their glass cages.

I now come to a phenomenon of a different charac-

ter, which shows in a completely independent manner the connection between the activity of the sun and the magnetism of the earth.

I refer to the magnetic storms.

The variations we have referred to are slow, regular, continuous variations of the elements of terrestrial magnetism. Besides these regular oscillations, which can be predicted for long times ahead, there are other oscillations, sudden and unforeseen, which in spite of their violence escape all regularity and occur by a sort of accident. It is almost as if in the ocean, besides the tides which impart a periodic rhythmic movement to the liquid surface, there arose storms and sudden tempests. In such a way there occur, beside the real daily oscillations of the magnetic needle, real magnetic tempests which make the compass needle "crazy," as the mariners say.

At certain times the mariner's compass is disturbed by sudden spasmodic movements. Their amplitude is often largely in excess of the total amplitude of the daily variation.

It corresponds to the force which sometimes amounts to a hundredth part of the total magnetic field, and occasionally the twentieth part of the total value.

This is what happened—to take only one example—in the night from the 22nd to the 23rd of March, 1920, when the needles of the magnetometers in the

observatories underwent an intense agitation which suddenly deflected, at Kew, for example, the needle by more than 3°, or 10 times its normal daily variation. At the same time a magnificent aurora borealis was observed in the whole northern hemisphere and down to very low latitudes. Also intense telluric currents interrupted telegraphic communication. At the same time astronomers found on the central meridian of the sun a large group of spots, one of which was 50 times the surface of the whole earth.

The synchronism of these diverse phenomena is not a chance coincidence. For many years in fact a large number of observatories have registered the number and importance of magnetic storms. The statistics based on these observations establish a striking parallelism between these phenomena and the sun-spot cycle. The magnetic perturbations have a mean periodicity of 11 years like the sun-spots, and that periodicity follows in every detail the curve representing the sun's activity. Lastly, and that is not the least singular fact, the number of displays of aurora borealis observed in every latitude where they are visible undergoes a cycle identical and parallel with that of the sun-spots.

There is one remarkable characteristic of the great magnetic perturbations which commence suddenly, like that of March 22nd, 1920. They are produced simultaneously in the most distant stations on the

surface of the earth, starting at the same instant. This proves that they are due to a cosmic cause.

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What is the exact nature and mechanism of this mysterious connection which links the activity of the solar surface with our magnetic storms? The detailed study of sun-spots and the corresponding perturbations of the compass must enlighten us.

The question has been asked whether there is a relation between the appearances of magnetic storms and the position of spots on the sun's disc. Opinions have been violently contradictory. Certain astronomers like Marchand, the much-regretted Director of the Pic-du-Midi Observatory, maintained that magnetic troubles always coincide with the passage of sun-spots across the central meridian of the sun. The American astronomer Veeder finds a coincidence at the moment when the sun-spots appear on the edge of the sun. Remember that the sun-spots revolve with the sun's rotation, which takes place in about 27 days. Tacchini, the Italian astronomer, and Hale, the American astrophysicist, to whom we owe the discovery of the magnetic field of sun-spots, have clearly shown that the relation linking solar disturbances with those of our magnets hardly depends upon the position of the disturbed region on the solar disc. I hope I may be excused from giving minute details. Father Sidgreaves, of Stonyhurst Observa-

tory, clearly confirms this. For example, the group of sun-spots which coincided with the great storm of 1920 had an area such that it took four days to traverse the sun's meridian. It is difficult to know which region of this group was most effective magnetically, and magnetic storms have often obviously coincided with spots very far from the central meridian.

There is therefore no special relation between magnetic storms and the position of sun-spots, or their heliocentric longitude, to put it correctly though pedantically. Every observer has noticed that the agitation of our compass-needles does not depend so much upon the size of the spots as upon their activity. Some spots are quiet and nearly immobile on the sun. Others are violently agitated, and change their shape at every instant, the spectroscope showing great displacements of material. A small but highly agitated sun-spot is more active in this respect than a quiet spot of immense extent. This agitation of sun-spots is best seen by the spectroscope, which shows the characteristic rays of the gases greatly distorted. This indicates rapid movements in various directions, according to the principle of Doppler-Fizeau.

At this point in our discussion we must put a fundamental question. Is it really possible that cyclones produced on the sun 93,000,000 miles away

disturb our compasses, while terrestrial cyclones do not? How can that be?

Since the link between the sun's activity and our terrestrial magnetism has been incontestably established it has excited general interest.

In vain has a rational explanation of this mysterious relation been sought. It is perhaps just on account of this unsolved riddle that so many spirits in the scientific world and outside are concerned with it. Some time ago the astronomer Young, whose work on the sun has advanced our knowledge considerably, wrote as follows: "It is difficult to imagine a satisfactory theory to explain the effect of solar disturbances upon our terrestrial magnetism . . . this magnetic relation proves that forces other than gravitation act across interplanetary space."

So long as the sun was considered incapable, apart from gravitation, of acting upon neighbouring heavenly bodies, except by the radiation of heat and light, the question could not be advanced. These effects cannot be explained by the action of temperature alone.

An attempt was then made to compare the sun with a gigantic magnet acting upon the earth as upon another magnet. But it is easily calculated that the solar globe would have to possess an intensity of magnetisation 10,000 times greater than that of our own globe to produce a variation of terrestrial mag-

netism discoverable by our instruments. This is all the less likely since matter loses its magnetic properties at high temperatures.

This hypothesis has been definitely disposed of by Lord Kelvin. The illustrious English physicist made a famous calculation in this connection. Considering a given magnetic storm of average amount he calculated that the variation of the intensity of the different magnetic elements during this perturbation, which lasted several hours, represented about 364 times the total energy of solar radiation. And he concluded his calculation as follows: "During the eight hours of this magnetic storm, which was a relatively moderate one, the sun would have had to produce, in the form of magnetic waves, as much energy as it regularly throws into space in four months, in the shape of heat and light radiation. This result seems to me completely to exclude the hypothesis that terrestrial magnetic storms are due to a direct magnetic action of the sun, or to any direct dynamic action of that body."

And Lord Kelvin concluded with some melancholy: "Up to now all efforts made in this direction have been fruitless."

It remains for us to show how this difficult step has been taken, how recent conquests of science have furnished the explanation of this magnetic telepathy by which the pulsations of the sun produce

palpitations of the sensitive steel of our magnetic compasses.

According to the above calculation of Lord Kelvin, the energy which reaches us from the sun, and which, if the sun were a magnet, would be necessary to explain these magnetic storms, is so enormous that it renders that explanation unlikely.

But truth may indeed be improbable, much more in astronomy even than in literature. It remained to prove that the explanation rejected theoretically by Lord Kelvin was proved false by the facts. It was also necessary to substitute other hypotheses which would themselves be plausible. And that, as we shall see, is what has recently been done.

As regards the first point, the answer has been given by the work of Hale and his collaborators on the subject of solar magnetism.

Taking the values of the magnetic fields observed by Hale in the sun-spots, it can be calculated that even if they were all of the same polarity the magnetic effect on our earth could not be detected by our instruments. And besides, they turn, like our terrestrial cyclones, in opposite senses in each hemisphere, and this produces opposing magnetic fields whose effects are neutralised at a certain distance from the sun. Our negative conclusion is thus corroborated.

As regards the total magnetic field of the sun discovered by Hale, it does not in any case exceed 50

units, which is a hundred times the field of the earth. It is easy to show by calculation that the sun's action on earthly magnets cannot be due to this any more than to the sun-spots. Thus Lord Kelvin's conclusions are clearly based not only upon probabilities, but upon realities.

The explanation of the sympathy which draws our compass-needles after the sun must therefore be sought elsewhere. It has been found in recent discoveries on electric radiations.

If the energy which causes the movements of the magnetic needle, its intense perturbations and phenomena connected with it, does not come directly from the sun, there is one means, and only one means, of escaping from the difficulties thus presented to us. It is by admitting that this energy is really upon the earth, and that the sun but liberates it. Thus the detonator of the shell liberates the enormous energy contained in the explosive. Thus also, to give a more suitable comparison, in ordinary or wireless telegraphy a very feeble electric current can bring into action an enormous force quite out of proportion to the feeble intensity of the waves through the intermediary of a relay.

Gauss wrote long ago : " If we eliminate unfounded fantasies we can only explain magnetic variations by electric currents circulating in the atmosphere.

" The atmosphere," Gauss admitted, " does not

conduct such currents any more than a vacuum. We are thus presented with a riddle."

The air at atmospheric pressure is indeed a bad conductor of electric currents. But this is not always the case with rarefied air—that is to say, air at high altitudes. This was unknown to Gauss, and was only revealed by later physical research.

Can there really be electric currents in the upper atmosphere? It is not sufficient that there is electric conductivity (and we shall see that such conductivity exists in the upper atmosphere). The mere existence of a copper cable does not bring about an electric current. It is also necessary that there should be between the ends of the cable a difference of potential, an electro-motive force like that produced by the Volta pile or the dynamo.

May there, or must there be in the atmosphere, causes which constantly produce electro-motive force? Yes, and these causes lie in the movements of that atmosphere, in the circulation of air created by them. These movements are produced partly by the rotation of the earth and partly by inequalities of temperature. Winds, and particularly the great regular winds, trade winds, and counter trade winds, are the effects of this circulation.

There is in electricity a well-known and extremely important fact—upon which indeed the theory and construction of dynamos are based: When a con-

ductor of electricity is displaced in the magnetic field the latter creates electro-magnetic forces which produce electric currents in the conductor. In the dynamo, coils of copper wire revolve in the magnetic field of an electro-magnet. It is this displacement which produces the electromotive force and the electric current.

Similarly, the circulation of the higher atmosphere gives rise to electric currents, since it displaces air in the magnetic field of the earth. It is true that that magnetic field is feeble. But on the other hand, the electric conductor, constituted by the upper atmosphere is thousands of miles long and tens or hundreds of miles in width. Even if the electro-motive force produced is feeble, the resulting electric currents can be of extraordinary intensity provided the air is sufficiently conducting.

The air at the level of the ground has a very feeble conductivity, as is proved by the fact that if an object charged with electricity is placed even upon a perfectly insulating support it gradually loses that charge in the surrounding air.

Recent researches have cleared up the mechanism of this aerial conductivity.

It is caused by radium rays which emerge everywhere from the earth's crust, and which "ionise" the air—that is to say, dissociate some of its atoms. Now "ionised" air becomes a conductor of electricity,

to an extent depending upon the strength of the ionising radiation. Thus, X-rays and radium rays enable gases to conduct electricity and to deprive a charged body of its charge when traversing the gas surrounding that body.

Knowing the extremely feeble value of the conductivity of the air near the ground, it is easy to calculate the conductivity of the upper strata of the atmosphere, supposing they were "ionised" by the same causes. Thus it is found that that conductivity, given the probable speed of displacement of the higher atmosphere, is still 100,000 times too feeble to give rise to electric currents capable of explaining the variations of our compass-needles. It follows that in its upper strata our atmosphere must be "ionised" much more strongly than near the ground.

Astrophysicists tell us that is necessarily the case, since—and here the chain of reasoning and fact is closed rigorously—the sun must emit strongly "ionising" rays which explain at the same time the electric currents circulating in the higher atmosphere, and why the currents influencing our compasses are in such close dependence upon solar activity.

To sum up: If the sun emits radiations capable of strongly "ionising" the upper strata of the atmosphere, these radiations and their fluctuations will suffice to explain, as we shall see, the regular or sudden changes of the magnetic elements. In this case the

sun only switches on the currents of the higher atmosphere by producing the necessary conductivity. It behaves like the very feeble waves of wireless telegraphy which switch on, by means of the coherer, the energy of the telegraphic relay at the receiving station.

In the case of the electric currents of the higher atmosphere, the energy utilised is that of the air movements loosed by the rotation of the earth, and it is entirely derived from those.

If we go over the famous calculation of Lord Kelvin we can calculate that even if every year produced a hundred perturbations of an intensity and violence equal to the largest ever observed, the corresponding energy derived from the rotation of the earth would, even after a million years, not suffice to retard that rotation by a single second per year. Thus, in this new conception all previous difficulties disappear.

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Now what can and must be the radiations emanating from the sun which ionise the upper atmosphere of the earth with a variable intensity and thus explain the connection between that heavenly body and our magnetic needles?

The first place among those radiations must be given to the ultra-violet rays of the sun. It has not yet indeed been proved that these rays can directly "ionise" the air, but we know that they can act on small dust particles. Therefore if the upper atmo-

sphere contains dust—which is not impossible—and if it carries the minute icicles of cirrhus clouds, the ultra-violet rays of the sun must more or less "ionise" the higher atmospheric layers. To explain the different magnetic variations we must then suppose that the ultra-violet rays of the sun are much more intense when the sun is covered with spots, and also that they emanate from those spots. All this is possible, but not yet proved. And then there is another phenomenon which we shall discuss further on, and which though closely connected with magnetic perturbations cannot be explained by the ultra-violet rays of the sun; this is the *aurora borealis.*

All these reasons lead us to suppose that the ultra-violet radiation of the sun cannot furnish a complete explanation of the observed phenomena. We must look for other causes.

A theory which has had many adherents, and has many still, is the ingenious and attractive assumption that the sun emits cathode rays.

This theory has been developed in its various aspects by Goldstein, Paulsen, Birkeland, Störmer, and also with great brilliance by Deslandres. We know that cathode rays consist of negatively charged corpuscles or electrons projected with considerable speeds in Crookes tubes. If a difference of potential is produced in a sufficiently rarefied gas, the negative electrode, the cathode, projects cathode rays through

the electric field. It is extremely probable that there is an electric field in the lower strata of the solar atmosphere. But in order that the sun should emit cathode rays it is necessary that the electrification of its atmosphere be the same as that of ours. We know that the surface of the earth is negatively electric with respect to the air, and this condition is favourable to an emission of electrons from the earth. Now several authors have arrived at the conclusion that the electrification of the sun must be opposed to that of the earth, and this makes it more difficult to conceive the emission of solar cathode rays. Another objection which has not yet been answered quite satisfactorily is that if the sun flooded space continually with negative electrons it would finally acquire a positive charge sufficient to stop all further cathode ray emission, since opposite electricities attract one another.

Another theory has been developed by the Swedish physicist Arrhenius. According to him, the electric action of the sun on the upper layers of our atmosphere is due to bombardment not of solar electrons, but of material particles, or of droplets much bigger than electrons also charged negatively, but which are expelled from the sun by the pressure of its light.

The phenomenon invoked by Arrhenius, the "Maxwell-Bartoli" pressure, is the same pressure which we used for demonstrating the possibility of

an interplanetary migration of living cells. This has taken us very far into the region of hypothesis, but it is a region in which it is sometimes pleasant to travel.

As regards the present subject, Arrhenius believes that the particles expelled from the sun by light must have a negative electric charge. That is indeed very probable, seeing that the condensation of dust and of drops takes place by preference about negative ions of gases.

But if the solar atmosphere is charged with an ever-increasing excess of positive electricity, a moment must arrive when its positive charge is such that it stops any further emission of negatively charged particles. This is the serious objection which we have already had to urge against the hypothesis of a solar emission of cathode rays.

On arriving in our atmosphere these particles would be relieved of their negative electricity by the ultra-violet rays of the sun, thus producing cathode rays which "ionise" the air. Thus in the theory of Arrhenius, it is again the cathode rays which govern the movements of our compasses; but these rays are produced in the atmosphere itself, and do not come directly from the sun.

Without wishing to deny that the process figured by Arrhenius might have some part in producing the magnetic variations, we must consider a point which

may deny them a preponderating influence. The point is that in the most favourable of cases the particles coming from the sun under the action of the pressure of light would require at least 40 hours to reach us from the sun.

Now it has been shown for several years, and in various ways, that in every case where it has been possible to report a magnetic storm of cosmic origin having a clearly defined beginning, and to connect it to an equally clearly marked perturbation on the surface of the sun, the beginnings of the two phenomena rigorously coincide. This means that the solar agent originating the magnetic disturbances reaches us with the speed equal to that of light. This has recently been confirmed in a manner which leaves no doubt by the work of Tringali, at the Observatory of the Roman College.

Since the principal solar agent of magnetic perturbation is propagated with the speed of light and therefore reaches us from the sun in eight minutes, it could not very well consist of the particles assumed by Arrhenius, which require a much longer time. Neither could it consist of cathode rays emitted direct by the sun, since the swiftest cathode rays known have a speed very much below that of light.

For all these reasons we are inclined to believe that the physical agent which causes the magnetic perturbations and variations consists of Hertzian waves

which, as we have seen in connection with the so-called wireless signals from Mars, must constantly emanate from the solar atmosphere.

Hertzian waves are propagated with the velocity of light. They have the property of "ionising" the rarefied gases which they traverse, being absorbed by them with the production of cathode rays. It is quite natural that as they are emitted from the sun's atmosphere they should be more intense when that atmosphere is violently disturbed—that is to say, in the place and at the times of sun-spots. This explains why the magnetic variations and disturbances are more frequent at those times. Finally, Hertzian waves are radiated in every direction by the electric discharge which produces them, contrary to cathode rays, which are only propagated at right angles to the electric field which emits them. This explains the observation that the magnetic disturbances of cosmic origin correspond to spots on any portion of the sun's disc.

These are some of the recent astrophysical considerations which explain the sympathies, formerly so mysterious, but now comprehensible, which link the sun across millions of miles with our mariners' compasses, just as they attach all earthly creatures without exception to his golden chariot.

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What is the future of the sun? Some people would

be astonished that anyone could take an interest in the destiny of a body situated at some 100,000,000 miles from the Observatory and very far away indeed from a modern drawing-room. They are wrong. It is the very future of our suffering humanity, and of its puny planetary support, which is bound up in the fate of the sun.

Have you ever tried to imagine what would happen if the sun were suddenly extinguished? The earth would be immediately plunged into an eternal night lit only by the twinkling stars. The moon would continue to accompany us in our wanderings, but it would be invisible, since its phases are only seen by reflected sunlight. Deprived of the divine warmth of the solar rays, our atmosphere would soon cool down. All water suspended in the air would fall in the shape of rain which would soon change into snow. The rivers would flood and then dry up. The entire oceans would congeal into ice, even before the gases of the air itself became condensed.

Plant life would stop in a few days. Then the animals would succumb one after the other. Mankind would carry on its existence a little longer with the aid of accumulated provisions and artificial heat. But soon these feeble reserves would be exhausted. In a month at the most all life on earth would be annihilated. Nothing would be left which now renders our planet so delightful and so detestable.

It would be the solution, an incontestably final solution, of all the burning questions which agitate humanity. And afterwards the other stars of the galaxy would continue endlessly on their silent way as if nothing had happened.

Soon the temperature of the surface of the earth would approach the absolute zero. Humanity would then long be dead. There would be nobody left to admire the wonderful landscapes formed by this cataclysm: the oceans transformed into rocks, with glaciers of carbonic acid snow down which would flow liquid cascades of the oxygen and nitrogen of the air.

From which we may see that the sun, the good old sun, is really the father and guardian of all earthly life.

Men are but little marionettes whose every movement and every gesture are governed by light golden strings, the beams of the sun. In reality we all have the same qualities of nobility as those Chinese Emperors who fondly hoped to distinguish themselves from their simple subjects by calling themselves Sons of the Sun.

In this the ancients were wiser than we. They adored and solemnly feasted the sun, seeing in him the father of all things below. The greatest ancient religions were religions of sun-worship: Indra, Baal, Moloch, Osiris, Mithra, Phœbus, and many other Egyptian, Peruvian, or Mexican idols were symbols

of the sun. The babouins of Upper Egypt, who greet the sunrise every morning with their cries, have the same tradition. Their loud and discordant incantations probably chant the divine sun in their own way.

Are not the majority of people inferior to these poor cynocephali, in giving no grateful thought to him? Have they not less soul than the trembling compass agitated by the golden hair of Helios?

The dreary picture which I have drawn of a catastrophe which, in all probability, will be a long time coming, reminds us opportunely that all our sources of energy are really of solar origin: waterfalls, winds, plants, and cereals, the animals which live on them, and coal. But how much wasted gold do not the sun's rays contain which fall upon us every day!

Their energy would suffice to melt every year a layer of ice 130 feet thick, surrounding our entire globe. This represents 265,000,000 horse-power. When our engineers transmit a few thousand horse-power over a few hundred miles, they expect to be admired, and rightly so. But what shall we say of the mechanism which, without any wires, transmits to us, over a distance of 93,000,000 miles, these thousands of millions of horse-power?

If the thousandth part of this solar energy could be utilised on earth, all the needs of human industry would be amply satisfied, social questions would be solved—and even the question of reparations. Let

engineers therefore hurry up and gather some crumbs of that prodigious power which Helios sheds upon them so uselessly, especially as the heat of the sun will not last for ever.

There are many differences of opinion as to what keeps up the heat of the sun for so many thousands of centuries. The enormous energy received by the earth is hardly the 2,000,000th part of the heat which the generous star radiates into empty space. What is it that regenerates this extraordinary dynamical reservoir, whose power seems to be undiminished since the dawn of history?

The gradual contraction of the sun suffices to account for part of it. The subsidence of materials towards its centre under the influence of gravitation produces heat automatically, as was shown by the great physicist Helmholtz. It suffices that every year, owing to this contraction, the sun's diameter (which it will be remembered is 860,000 miles) diminishes by only 500 feet—that is, a little more than the 10,000,000th part of its value—in order to restore the heat constantly lost. At this rate it takes nearly 30,000 years to diminish the sun's diameter by a quantity appreciable to our most sensitive instruments. It can be shown by calculation that before it becomes too dense to allow this concentration to continue, the sun will send us its life-giving beams for 6,000,000 or 8,000,000 years to come.

That is somewhat reassuring concerning the immediate future of our two-footed species. But will 6,000,000 years be long enough to see humanity at its present rate of progress emerge from barbarism? I should be very chary of replying to this pessimistic question if radium had not come as a *deus ex machina*.

That was what the ancient tragedians called a god who descended from the ceiling of the theatre by means of pulleys, windlasses and other machines when the situation had become inextricable, and by whom, at a given moment, innocence was recognised, virtue honoured, and the villains were suitably chastised. These things sometimes happen in a theatre in spite of the rule which prescribes that it should be the mirror of life. It is astonishing, in this connection, that in the presence of such an ingenious artifice certain Greek philosophers should have dared to maintain that their personal gods were useless hypotheses which did not solve any difficulty.

Now, thanks to radium, we can regard the duration of the sun's heat under a new aspect. It is well known that radium spontaneously and continuously evolves heat. The amount of heat developed by one gramme of this body in one hour would suffice to raise one gramme of water from freezing point to boiling point. Now there is no doubt that radium exists in very large quantities in the sun; the spectro-

scope has indeed revealed the presence of large quantities of helium in its atmosphere, and this is one of the products of the disintegration of radium. Two grammes of radium per ton contained in the sun would entirely regenerate the heat lost continuously. We still lack numerical data on the exact proportion of radio-active materials contained in the sun. But henceforth we may, even at the lowest estimate, extend the future duration of solar heat far beyond the previous limit, though it may be only to prolong the agony.

There is another new and bold hypothesis which is very plausible. It is that the formidable pressures amounting, according to recent researches by Jeans and Eddington, to some 20,000,000 atmospheres, obtaining at the centre of the sun, would suffice to regenerate indefinitely the radio-active bodies by acting upon the lighter elements falling from the surface.

But then it is perhaps not by cold but by excess of heat that terrestrial life will be finally terminated, and we know that no organised being can survive 350° above zero. Henri Poincaré has shown indeed that many causes, especially the resistance of the interstellar medium, accelerate the movement of the planets, which will finally fall into the sun. That will happen after an enormous time, which formerly was thought to be subsequent to the extinction of the

sun. But radium has put back the latter date so far that the contrary becomes more probable. Thus, according to the most recent theories, it is probably not cold which will annihilate earthly life. Life will be volatilised in that grand crematorium the sun. Humanity will perish like those moths who, attracted by a flame, and drunk with light, fly in and burn their wings.

Calculation shows that our fall into the sun will prolong the sun's radiation at its present rate by 95 years and 19 days. That will be the first and only time that the earth will have done something sufficiently important to be observed by those celestial inhabitants which possibly gravitate round the blue Sirius. It will be an ending in beauty.

That science still hesitates between heat and cold as the method of destruction of our species proves that there is still some uncertainty about it. Let us not mock at this. The important point on which men of science are unanimous is that we still have before us at least several hundred thousand centuries.

That is enough to do many great things and also many stupid things, under the vast impassive sky, which to-day is the starry banner, and to-morrow will be the immense shroud of the human army.

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The sun which has shone for millions of years, as shown by geology, and the sun which will shine for

hundreds of thousands of centuries, can we call it old, or can we call it young? Is it either of these things any more than the rose which blooms in the morning and fades in the night? It is a question of sentiment, and is not in my purview.

For those who reason in the domain of sentiment, be it ethics, faith, or art, every doctrine is true. The most perfect music, the greatest idea of justice, the most beautiful colour, is that which best harmonises with their desire or their imagination.

We poor gleaners of truths have not that privilege. When in order to explain a small fact of experience we have painfully, in the course of centuries, built up a hundred theories, there is only one which is found exact—the hundred and first.

CHAPTER IV

THE GIGANTIC STRUCTURE OF THE SIDEREAL UNIVERSE

Distances and distribution of the stars—Modern measurements of parallaxes—The map of the heavens—Proper movements and star-drifts—Structure of the Milky Way—Star-clusters—Spiral nebulæ—The great hypothesis of Island Universes.

THE results recently obtained in stellar astronomy are calculated to humble our geocentric and even our heliocentric pride. Our sun, with its retinue of negligible planets, only appears now to us as an insignificant island in the sidereal ocean, as a grain of sand on the seashore. But after all, those studies which show us our smallness in space are less humiliating than one is apt to think. They also enable us to admire the power and beauty of the methods devised by the human brain, which enable us to measure, to embrace, and to conceive, an ever-growing universe.

The world of stars now reveals to us its chemical constitution, its individual and collective movement, its age and the degree of evolution of its members, their temperature, and the rhythm of its diverse pulsations. All this has furnished of late an ample harvest of discoveries. But before entering upon

those studies which concern, so to speak, the physiology of the stellar universe, a fundamental problem presents itself, that of the distances and dimensions of that universe—in other words, its anatomy. We cannot explore the structure of its organism without knowing the distances of its elements.

How can we measure these distances in spite of their enormous extent? I shall first show how methods have been singularly enriched and developed. I shall then indicate the astonishing results attained by these methods—results which, in spite of their almost fantastic character, will not appear incredible as soon as we understand how they are arrived at.

The distance of the nearest stars is measured by a method identical in principle to that by which a surveyor determines the height of a point which cannot be reached, such as the summit of a steeple.

What does the surveyor do? He focusses a small telescope upon the steeple, placing himself at a certain distance in one direction or another. He repeats the process at another distance, and a level attached to the instrument measures the angle of the line of vision to the horizon. Two such points and the distance between them, or what is called the base-line, are sufficient to deduce the height of the steeple. The angle under which the two successive points would be seen from the steeple is called the

"parallax" of the steeple in astronomical language.

It is therefore by a method of surveying that the distances of the nearest stars have been determined. For the moon, for instance, the base-line chosen was that between two points on the earth's surface, one in France and the other in America.

It is clear that the measurement is the more exact the longer the base-line. To measure the distance of the sun and the nearer planets, the base-lines available on the earth have been sufficient, the longest being the diameter of our globe itself, about 8,000 miles. This length did not suffice, however, for measuring the distances of the stars, as it became clear at once that they were infinitely farther away than our sun. On focussing a telescope on the brightest of the stars from two points of the earth's surface as far apart as possible, it was found that the lines of vision of the two telescopes were absolutely parallel within the limits of error. This meant that the distance of these stars was practically infinite with regard to the dimensions of the earth, and that a longer base-line was necessary for these measurements.

This longer base-line was obtained by focussing upon the stars at an interval of six months, when the earth is at the two ends of the diameter of its orbit around the sun. Thus the diameter itself was

the base-line. Since its length amounts to about 186,000,000 miles, it is 25,000 times longer than the longest terrestrial base-line.

Thus for the first time the distances of several stars were measured.

In spite of the enormous length of the base-line, the angle which joins the stars to its ends is so small that it required the whole precision of methods and astronomical instruments to reveal it.

It has been agreed to call the parallax of a star the angle subtended by the radius of the earth's orbit as seen from the star.

The parallax of the star nearest to ourselves is an angle of less than one second of arc. Now, what is a second of arc? It is the angle under which one sees two objects when the distance at which they are seen is 206,265 times greater than their distance apart. For instance, it is the angle under which we should see a circle one yard in diameter, placed 206,265 yards away, or it is the angle under which we should see an object of one millimetre placed at 206 metres. The parallax of the nearest star does not attain this value. In other words, the distance of the nearest star is more than 200,000 times the length of the base-line by which it has been measured. This implies that that star is more than 400,000 times farther away from the earth than the sun itself, which has a distance of about 93,000,000 miles.

In order to illustrate this by a concrete example, I may mention that the nearest star was until recently thought to be the star Alpha in the constellation of the Centaur, which is visible only in the southern hemisphere.

The parallax of this star is three-quarters of a second of arc. Its distance from the earth is 270,000 times greater than our distance from the sun, being 25,000,000,000,000 miles.

But a new fact has recently come to light in this domain. The English astronomer Innes has discovered that the nearest star is not Alpha of the Centaur but another very small one placed in the same region, whose parallax is 0·79 of a second of arc. That is the nearest star hitherto known. It has been called *Proxima Centauri*. It has only recently been observed, as it is very faint, being of the thirteenth magnitude, whereas Alpha Centauri is of the first magnitude. And it was by photography that Mr. Innes neasured this parallax.

This curious star offers another singularity in that it has among all known stars the smallest actual brightness. Its luminosity, or the total quantity of light emitted by it, is only the 2,000th part of that emitted by our sun, which is by no means one of the brightest of the stars.

It follows from all this that it is inconvenient and pedantic to express the distances of the stars in miles,

since we thus get numbers with which our imagination is not familiar, and which by their mere size fail to represent anything precisely. We must therefore express stellar distances by means of more adequate units.

This has been done by means of the velocity of light. Light traverses about 186,000 miles in one second (which is about 8 times round the earth at the equator). It takes little more than a second to reach the moon. It takes 8 minutes to traverse the distance between the sun and earth. It therefore takes 4 years to reach the nearest star. This example shows the convenience of expressing stellar distances by the time required by light to cover them. The "light-year"—that is to say, the distance covered by light in one year—has been adopted for some time in order to express sidereal dimensions.

This unit had something pleasing to the imagination since time lent wings to space. But it had the inconvenience of having no simple numerical ratio to the parallaxes, or the angles by means of which astronomers are also in the habit of expressing the distances of stars.

For this reason, a new unit has been recently employed in astronomy. It is the distance which corresponds to a parallax of one second. This international astronomical unit, very convenient and now generally adopted, has been called the *parsec*,

a name which ceases to be strange when it is remembered that it is formed from the first syllables of the words "parallax" and "second." It expresses clearly to everybody what it means, since both words are common to the principal civilised languages.

A parsec is equal to 206,265 times the mean distance of the sun and the earth. A parsec is therefore equal, as a simple calculation will show, to a little over three light-years, or to 3·256 precisely.

Photography has allowed us to multiply the direct measurements of stellar distances by means of triangulation from a base-line containing the successive positions of the earth at intervals of six months. On the negatives made after six months the nearest stars appear periodically displaced among the distant stars, which themselves remain immobile. The effect is called the annual parallax. From the amounts of these displacements observed with the micrometer the required parallaxes are deduced.

By these methods the distances of the stars whose parallax is not less than 1/20th of a second of arc, and whose distance does not therefore surpass 20 parsecs, or 4,000,000 times the distance of the sun, have been exactly determined. But most of the stars are much farther away yet, and other methods have had to be used to measure their distance.

In this connection the ingenious and fruitful idea of using as the basis of the triangulation, not the

diameter of the earth's orbit, which with its 186,000,000 miles is but a small thing in space, but the ever-growing distance covered by the whole solar system has been successfully employed. Herschell had already remarked in connection with the proper motions of the stars, that is to say, their changes of position from one year to another, that these apparent movements could be partly due to a displacement of the sun and its retinue of planets.

If you walk in the evening along the Avenue de l'Opéra, beginning at the Théâtre-Français, the standard lamps which illuminate the Avenue and the lighted windows of the houses will appear to separate out as one approaches them, and will appear to move together as one walks away from them. It is the same in the sky. It has been observed that in general the proper motions of the stars are such that certain constellations seem to grow and expand in some way from year to year, whereas the constellations on the opposite side seem to contract and their stars seem to join each other. It follows that the sun moves in the direction of the former, and away from the latter. The direction in which we seem to be carried, and which is called the apex of the sun's motion, is not far from the beautiful blue northern star known by the name of Vega. The spectroscopic methods which I have mentioned, and which employ the Doppler-Fizeau principle, enable us not only to

determine the direction in which the solar system moves, but even to determine with precision the speed of this displacement, which is 12 miles per second, relative to the whole system of the stars. This movement transports our system in the course of a century to a distance over 400 times the distance separating the sun and the earth. It therefore furnishes for the triangulation of the universe a base-line which at the end of 20 years is 40 times as great as the diameter of the earth's orbit.

The approximate distances of a great number of stars have been determined by this method.

A process connected with this has also been much used. It is no longer founded on the study of the displacement of the stars, but on the photometric comparison of their apparent brightness. It is known that the brightness of a source varies inversely as the square of the distance, being reduced to one-quarter when the distance is doubled, and to a hundredth when the distance is increased tenfold. It is reasonable to suppose that the stars have everywhere on the average somewhat similar real brightnesses. This method has furnished precious information which agrees with previous results.

I now come to some extremely ingenious and novel methods. They are physical and not geometrical methods, and they have recently given us a stupendous outlook upon the distances of certain groups of stars

which formerly appeared to be altogether beyond our limits of computation.

Here is first of all the curious procedure proposed by the American astronomer, Adams.

It had been noticed that the relative intensity of the lines of a given spectrum—such as the spectrum of iron—depends on several physical conditions, and particularly on the pressure under which the vapour of iron becomes incandescent. Different stars sometimes have very different dimensions and masses, and hence the pressure at the surface of the photosphere (which radiates their light) must vary from one star to another. It was therefore to be expected that we could observe in the relative intensities of stellar spectrum lines certain differences which would enlighten us concerning the masses and relative sizes of different stars of the same spectrum type.

This is just what Adams has found. In comparing stars of known distance and known real brightness, he found differences in the relative intensities of the various spectrum lines corresponding to a given metal. The greater the differences between the total brightness of the stars the more intense are certain lines. Applying the same process to the whole series of stars whose distances, and consequently whose brightnesses were known, he found a constant relation between the brightnesses and the relative intensities of the spectrum lines. So Adams pro-

posed to deduce the relative luminosities of the stars from the relative intensity of these rays. Thus he found, for instance, that in the case of a given star of the same apparent brightness as another star whose distance was known, the actual brightness was nine times greater than that of the latter. Consequently it would have to be three times farther away from us. Such was the case. The results so obtained for a fairly large number of stars are found to agree with what had already been determined from the geometrical measurement of their parallaxes. It is therefore quite reasonable to generalise the method.

Here we have a process with an immense future, which allows us by a simple spectroscopic study of light to ascertain the distances of the most distant stars. The applications of the method are practically unlimited, since it is applicable whenever the light of a star is intense enough to be analysed in the spectroscope. Finally there is another kind of star among variable stars, the study of which has opened up to us a way into hitherto inaccessible depths of stellar space. These are the Cepheids, thus called from the best-known star of that type, Delta in the constellation Cepheus.

That star increases in brightness for a certain number of hours; then having reached a maximum it wanes, but more slowly, down to a minimum, after

which its light quickly increases again and repeats the same cycle indefinitely. This particular rhythm of the Cepheids has some resemblance to the tides which in our oceans continually rise and fall in something like the same fashion.

These Cepheid variables have recently acquired a capital importance in stellar astronomy. That is because a simple and direct means has been found of ascertaining their real brightness, and hence also their distance.

An American astronomer, Miss Leavit, of the Harvard Observatory, whilst studying a fairly large number of Cepheid variables found in a small star-cluster called Magellan's Cloud, noticed that the length of their variable period, or the time which separates two maxima or two minima, depends very closely upon their relative brightness. All the stars of the little Cloud of Magellan are thus no doubt physically linked, and therefore are nearly at the same distance from us. Now it is found that among the Cepheids of this cluster the brightest—that is to say, the largest—have a period of variation longer than that of the smaller ones. This period varies for the Cepheids of this cluster from 1 day to 127 days, and Miss Leavit has proved that there is a simple numerical relation between the real magnitude, or rather the real brightness, of a Cepheid and its period of variation. This law, which agrees with certain conclusions

of stellar dynamics—into which I need not enter here—has been verified in the case of other star-clusters containing Cepheids, and also in several relatively near bright Cepheids, whose distances are known by direct measurements of parallax. The law has always been found to be rigorously exact.

Thus it is known that the real brightness of a Cepheid whose period of variation lasts one day is a hundred times greater than that of the sun; that when the period is one of 10 days its brightness is 1,500 times that of the sun, and so on.

This method has enabled us to know the real brightnesses and therefore the distances of a great number of stars, and thus has enabled us to sound unexplored depths of the sky.

It now remains to enumerate the surprising results of all these vast soundings of the universe.

It shows at all events that in the chaplet of the stars our yellow sun is only a ridiculous little amber bead. As regards the things which turn round that bead, the less said the better.

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Photography has played and still plays an essential part in all these measurements and numberings which have revealed the structure of the sidereal universe, or at least the little we know of it.

Considering that the measurement of the exact position of every star observed in our telescopes takes

several minutes; also that there are more than 6,000,000 stars down to the eleventh magnitude, and more than 400,000,000 down to the fourteenth magnitude, the preparation of a complete chart of the heavens originally appeared to be a superhuman enterprise. But photography had not then been taken into account. Thanks to photography it is now possible to register in a few minutes on a plate tens of thousands of stars which obediently come and inscribe their own relative positions.

The photographic plate which fixes the flying moment and revives at will that which has perished has become the mirror of the sky itself. The grains of sensitive silver imprison for us an image of the whole firmament.

Thus was born the idea of a vast photographic directory of the stars, the first portion of which, comprising stars down to the eleventh magnitude—that is to say about 6,000,000 stars—is now finished. At the present time the 22,154 negatives, corresponding to as many small squares into which the celestial vault has been, so to speak, divided, have all been obtained.

This work has been carried out by 18 observatories, distributed all round the earth, which have divided up the work in a harmonious collaboration.

The nations do not always understand each other in dealing with this little planet. We have noticed

on the other hand that whenever zones of influence have been marked out in the planetary system, or "mandates" in the Milky Way, they have come to agreement without the spilling of blood, and proceeded together to the pacific penetration of the vast universe. Let this console us for that.

If, by the way, the photographic chart of the sky is an international achievement, it is French astronomy which has had the honour of creating it and bringing about its adoption by other nations. It has also designed the photographic telescope, or astrograph used in this enormous work.

The documents obtained, supplemented as they are by some deeper soundings made with instruments more powerful than the Kodaks of the photographic chart, have yielded a great harvest of discoveries.

In the first place they have enabled us to distinguish a great number of variable stars, and new small planets circulating between Mars and Jupiter.

That is not all. If the stars were on the average as numerous in the neighbourhood of the sun as in the more distant regions of the universe, calculation shows that there would have to be on the negatives four times as many stars of the seventh magnitude as of the sixth, four times as many stars of the eighth magnitude as of the seventh, and so on. *Now, the census of the negatives shows that there are only three times more approximately, and not four.*

The conclusion is that the sun is not far from the centre of a fairly dense group of stars which may either be the Milky Way, or an assemblage which is more localised, but included within the Milky Way.

This heliocentric hypothesis is very flattering to our pride, for on the scale of sidereal distances heliocentric and geocentric views are practically identical, though the prosecution of Galileo once put them into violent opposition. But that prosecution was a little local case, a parish quarrel. Will the chart of the heavens revive our conceit which had received so many blows? Will it allow us again to consider our system as the centre of the stellar universe, and the latter as a charming frame, solely designed to contain, like a medallion, our egoistic vanity?

Alas, no, for a closer study of the distribution of the stars shows that the sun, though not on the confines of the galactic system, is yet found in an eccentric situation. Several thousands of light-years separate us from the probable centre of this ring.

This eccentric position helps us to understand one of the most curious discoveries made on the negatives of the celestial chart. This discovery made by Professor Kapteyn, of Groningen, has since been fully confirmed. The sidereal movements do not take place equally in all directions. The measurements prove that most of the stars photographed can be divided into two groups which cross each other, and

which are directed towards points of the heavenly vault separated by an angle of about 100°, and therefore not entirely opposed to each other. Within these two star-drifts stars have individual movements, which are superimposed upon the double drift discovered by Kapteyn.

The interpretation of all these facts is hardly begun. Innumerable hypotheses, most of them contradictory and incapable of proof, have already been advanced. The most probable one is that the Milky Way is a spiral nebula, and that from our more or less eccentric position we observe the two spiral trains of stars which proceed from the centre of the nebula in two opposite directions.

The photographic and visual gaugings have led to the conclusion that our galactic universe comprises about a million and a half stars.

Some astronomers have assumed that if our telescopes had a much bigger range they would discover more stars than we see now. But then the mean proper motions would have to be much more rapid at the centre of the mass, as has been shown by Henri Poincaré. Thus Poincaré's calculations contradict the hypothesis of an indefinite extension of the stellar universe, since the number of stars counted agrees fairly well with the number calculated.

We shall see at the end of this volume, in connection with the rotation of the earth, that quite recently

Einstein has come to a similar conclusion with regard to the finite extent of our universe.

All these results are nothing in comparison with those which our grand-children will discover when they renew the photographs of the sky century by century, and can see at a glance the changes in the universe. Projecting upon a screen the negatives made to-day, those made in the interim and those made in the latter times, they will see the most wonderful of films, which will review in a few moments the age-long history of the world with its vicissitudes, its suns which are extinguished, or are suddenly born, and the long procession of mute stars behind the coffin of Time.

The ancient Egyptians believed that everyone has a double who is his faithful image and who survives him at death. The photographic plate has materialised this graceful dream. It has given us to-day a "double" of the entire heavens. The marvellous things which our microscopes have seen through its robes of glass and transparent gelatine are probably nothing to that which the future will unveil.

Taken as a whole, and taking into account the methods of measuring distances which have been passed in review, the Milky Way presents itself in the form of a spiraloid structure whose thickness is barely half its greatest length. The latter amounts to about 30,000 light-years. It therefore requires

about 300 centuries in order that a ray of light—which reaches us in 1 second from the moon, in 8 minutes from the sun, and in 4 years from the nearest star—shall traverse the galactic system. That ribbon of dim light which the night wears as a bandolier or a light scarf surpasses in extent all that has been dreamt of before.

Then what becomes of the simple Greek legend according to which the Milky Way arose from a few drops of milk which the infant Hercules let fall from the bosom of Juno? However charming this fable may be, we may give greater admiration to the intuitive profundity of Democritus, who wrote 25 centuries ago: "The Milky Way is composed of stars which are, however, on account of the prodigious distance which separates them from us, too close together to be discerned separately."

When Democritus wrote that the light which comes to us from the confines of our stellar archipelago had nearly accomplished its journey. What we observe there now took place long before humanity had a history. These things are as far away in time as they are in space.

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This is not all, for on the twin wings of sight and thought we shall traverse spaces even more vast, to study those astonishing objects which are called globular star-clusters.

If we examine or photograph with a more powerful telescope the different zones of the celestial vault, we find that the stars are not uniformly distributed. In certain regions, such as the constellations of the Giraffe, or the Snake-charmer, the stars are comparatively scarce. They are much less so in Orion or the Great Bear. In these two latter constellations it is found that the principal stars forming them are not only grouped by chance perspective, as in nearly all the rest of the sky, but that they are really physically connected. Thus the stars of the Great Bear have the same sort of velocities and proper motions, and this cannot be due to chance, but proves that these stars form, according to the usual expression, a physical stellar system. We can easily prove by means of the telescope the existence of other physically linked star-groups, and among them the curious Pleiades visible with the naked eye in the northern hemisphere and known from the most ancient times.

Continuing this research we finally come to small close groups of stars, or small stellar clouds, which on account of their shape are called globular clusters. These stars, or rather groups of stars, are generally invisible to the naked eye. In low-power telescopes they are seen as small faint round patches. Messier, who became famous in the eighteenth century by observing them, knew them only as nebulosities without stars, as did his predecessors. They were

vaguely classified for a long time as nebulæ. Sir William Herschell and his son succeeded with their powerful telescopes in showing that these small round nebulæ consist in reality of myriads of stars. Thus arose the distinction between nebulæ which can and nebulæ which can not be resolved into stars. The former are now called with greater precision star-clusters.

The number of stars in clusters is very variable. We distinguish between open clusters (such as the Pleiades, the constellation of the Great Bear, etc., where the stars are physically linked without being strongly concentrated), and the star-clusters that are so close as to be almost fused together.

It is a curious and striking circumstance that while the increase of optical power of instruments has revealed to us the correspondingly greater number of stars and nebulæ, it has not given us a single new star-cluster for the last fifty years. The number of these objects known to-day, which barely equals eighty, is the same as half a century ago, and the era of discovery of such systems seems to be terminated, which is not the case with any other type of celestial object.

To bring these generalities to an end, I shall add that the number of stars observable in star-clusters surpasses everything one can imagine, especially if rather long photographic exposures are made. In

the middle of the negative the images of the stars are superimposed upon one another, and give a cumulative impression which is all the more extraordinary as we have to deal with suns the smallest of which is much more brilliant and massive than our own. On recent photographs of star-clusters, obtained with modern telescopes of great luminosity and resolving power, the stars round the central portion are reckoned in tens of thousands, and in the centre they are so closely packed that they cannot be resolved.

The apparent space occupied in the sky by these globular star-clusters is very variable. The great cluster of the Centaur in the southern hemisphere has an angular diameter double that of the moon. Several other clusters have diameters equal to that of the sun or the moon, but most of their diameters are less than five minutes of arc.

The globular star-clusters have a strange peculiarity. Their distribution is very anomalous. They are not uniformly distributed over the celestial vault, nor collected like the stars along the Milky Way. But they only appear on a hemisphere of the sky which has its centre on a point in the Milky Way. In order to indicate the position of this centre precisely, we may say that it lies in the southern constellation of the telescope, at a point of right ascension 17 hours 40 minutes, and a polar distance of 125°.

Certain astronomers advance the explanation that the system of star-clusters is situated in space at the centre of the Milky Way, while the position of the solar system is a little eccentric. Others, on the other hand—and I incline to their opinion—suppose that the sun is not very far from the galactic centre, and that the star-clusters are really grouped very eccentrically on one side of the Milky Way. In both cases the star-clusters would make or form an integral part of the vast galactic star system, and would make the latter, or at least its extensions, much vaster than ever before.

And now we can follow Mr. Shapley in a more detailed study of one of the globular star-clusters also situated in the constellation of Hercules. It is known by the name of Messier 13, which means that it is the 13th on the list of star-clusters compiled by Messier.

It is an object of impressive beauty, a swarm of silent and crowded celestial bees, each one of which is a gigantic sun. Many years ago I had occasion to photograph it with a long exposure, by means of the wonderful 100-centimetre reflector of the Meudon Observatory. Without the actual experience one cannot imagine the æsthetic and emotional impression produced by the image of these millions of concentrated suns caught on a square centimetre of gelatine.

The great 60-inch telescope of the American Observatory of Mount Wilson lends itself even better

than that of Meudon to the examination of this ant-heap of stars. Thanks to its great focal length, which is 25 feet, and can be lengthened to 80 feet, it easily separates the stellar images of the centre of the mass. On a photograph of Messier 13 taken with this unique telescope we can already find, after only 2 minutes' exposure, more than a thousand stars. On prolonging the exposure to 11 hours an image is obtained on which Professor Ritchey was able to count 30,000 stars brighter than the 21st magnitude.

Applied to the Hercules cluster the methods for determining parallaxes described above show that it has a parallax slightly inferior to a 10,000th of a second of arc, which corresponds to a little more than 36,000 light-years.

Even the boldest imagination shrinks from conceiving what such a distance represents.

Expressed in miles this distance would be indicated by the number 22 followed by 16 ciphers, and it would be correctly described by saying that it equals 220,000 billion miles. That is 10,000 times greater than the distance to the nearest star, that Proxima which has already been mentioned. It is about 2,000,000,000 times the distance between sun and earth. It is 5,000 times the distance of Sirius.

That would have greatly surprised M. Renan, who thought that he could survey the earth from the greatest possible distance when he invented the

famous "point of view of Sirius." The greatest philosophers have these weaknesses. In reality Sirius is a sort of suburb of ours. One must be a little short-sighted and have, philosophically speaking, a minimum range of distant vision if earthly things are only to be regarded from the point of view of Sirius. It is a deplorably anthropocentric point of view.

But let us leave this narrow circle without an horizon and return to the cluster of Hercules.

The ray of light which reaches us thence to-day, and is gathered up by our telescopes, started on its way 36,000 years ago. If we remember that the Christian era only goes back about 20 centuries, and that the whole history of humanity does not amount to 80 centuries, we can conceive what these numbers represent. The Hercules cluster could have disappeared 360 centuries ago, or it might have been smashed up since and yet we should know nothing about it.

During the time since this celestial object emitted the swift light-ray which reaches us now after having travelled without cessation on the wings of its stupendous velocity across the icy spaces of the heavens, a thousand human generations have appeared and disappeared. Civilisations now dead in the memory of men have flourished. Empires whose very name is unknown to us have been built up in blood and

suffering by conquerors proud of the unforgettable and permanent work they sought to erect. Where are these empires and these people? What were they called? Yet these hundreds of centuries of which the trembling ray of Messier 13 is the distant messenger, are but a little while in the cosmic evolution of any stellar system.

How can one help admiring that astronomical science which by interpreting distance in terms of time is of all the sciences best able to make us touch the past with our finger, the only science which makes it present and enables it to survive?

Yet there is something still greater than those incredible distances which it measures, and that is the fragile human brain capable of surveying and conceiving these distances.

Knowing the parallax of the Hercules star-cluster a crowd of other deductions follow. In the first place, we can deduce its absolute brightness, or, as it is called, in the more usual but less correct language of astronomy, the "absolute magnitude" of the principal stars of this cluster. Knowing that these stars are of the 13th magnitude, and that at their distance the sun would be as feeble as the 20th magnitude, it follows immediately that the brightest stars among them are 2,000 times brighter than our poor little sun.

We may also find the dimensions of this globular

mass. They are enormous. Its diameter equals 350 light-years. A star situated at the same distance from the earth as Messier 13 would require 100 times the brightness of the sun in order to be visible to the naked eye.

Besides, the stars of the Hercules cluster are much closer together than those which surround the sun. If we trace out from the centre of the circle, or rather of its photographic image, a circle having for its diameter the distance between the sun and our nearest star, it is found that this circle contains a large number of stars. The concentration, or, so to speak, the density of stellar population, is therefore much more considerable in this cluster than in the relatively desert region inhabited by our solar system.

It has been finally discovered by the spectroscopic method of radial velocities that the Hercules cluster as a whole moves with the considerable speed of 185 miles a second. This volley of lead-shot fired through celestial space by the gun of gravitation represents from the ballistic point of view a momentum difficult to conceive, especially if we remember that the mass of the whole cluster is no doubt greater than that of 100,000 suns.

The study which we have made of the cluster Messier 13 has been extended to all the other globular star-clusters known, particularly by Mr. Shapley. The conclusion of these researches is that the nearest,

and also the most brilliant cluster, that of the Centaur, is at a distance from us equal to 650,000 parsecs (remember that one parsec is equivalent to 3 years and 3 months traversed by light and corresponds to a parallax of 1 second of arc). The most distant of the clusters, which goes under the name of N. G. C. 7006 (astronomical terminology is somewhat peculiar), lies at a distance of 67,000 parsecs. Light requires 217,000 years, or 2,170 centuries, to reach us from there. The centre of agglomeration formed by this cluster is about 20,000 parsecs away from us, and we are on the confines of this agglomeration, which explains why we see it on only one side of the sky.

Quite recently Mr. Shapley has extended these studies to the open clusters, employing similar methods. The distances found for these lesser objects are comprised between 80 parsecs for the Pleiades and 18,000 parsecs for another cluster. The mean of their distances is 6,000 parsecs, and the centre of their agglomeration is about 3,000 parsecs from the sun in the galactic longitude of 270°. Mr. Shapley thinks that the open clusters are the remains of globular clusters which have been dislocated and spread out fan-wise as a charge of shot would be in air, to return to the example of shot-gun.

In this connection we may also draw attention to the very curious and suggestive researches recently carried out by the Swedish astronomer, H. von

Zeipel. He has endeavoured with success to apply on an infinitely large scale, in the case of the star-clusters, those statistical laws of the kinetic theory of gases which are obeyed in the infinitely small by the gaseous molecules. His results seem to show that the same laws are applicable to both. This opens a most promising vista to the whole of stellar dynamics. It adds a new link to the eternal chain conceived by the poets and philosophers, but forged by the men of science, which brings the infinitely great and the infinitely small into the communion of the same harmony.

When Sir William Herschell began, more than 100 years ago, to resolve a great number of nebulæ into stars, he first thought that all nebulæ would be resolvable. A closer observation of the phenomena led him, however, to the conclusion that beside these gatherings of stars there really existed in celestial space nebulosities formed of a brilliant and continuous fluid which could not be separated into stars. Under the influence of his son, John Herschell, and Lord Rosse, it was again thought that all nebulæ could be resolved. Shortly afterwards it was found necessary to return to the dual nature of nebulæ which had been guessed at by William Herschell with such marvellous intuition.

It is the spectroscope which in this respect furnished the decisive data, especially in the hands of the great

English astrophysicist Huggins. He showed that a certain number of nebulæ are characterised by a discontinuous spectrum crossed by brilliant lines due to gases, among which he found hydrogen and another element still unknown on earth which has been called "nebulium." Besides these clearly gaseous nebulæ the spectroscope indicated that several others had a continuous spectrum resembling that of the stars, and could therefore be agglomerations of suns apparently extremely close together on account of their great distance.

Among the nebulæ with a continuous and non-gaseous spectrum there is a class of bodies which were formerly considered rare, but of which an enormous number is known nowadays. I refer to the spiral nebulæ.

The spiral nebulæ are small and vapoury spots which can be observed on photographs of several parts of the sky, and formed by two spirals rolled together, like delicate silver snails exhibited in the garden of the stars.

In past years such a vast number of these spiral nebulæ has been discovered that to-day they represent after the stars themselves the most profusely scattered bodies in the universe.

Mr. Curtis of the Lick Observatory, California, who has made a close study of these problems, estimates that at the present time the number of spiral

nebulæ observable with modern instruments is about 1,000,000.

What are these singular bodies that are so abundant in space ?

Well—and here the imagination is somewhat staggered—it seems more and more clearly proved that every one of these spiral nebulæ is in reality a complete stellar universe corresponding to our galactic system.

The analogy between the spiraloid form of the Milky Way and that of the spiral nebulæ would, of course, be insufficient to prove their similar constitution.

The comparison, now justified and admitted by most astronomers, is the fruit of various recent researches made with the help of the most delicate methods of astrophysical analysis. Their results, which I shall now indicate, agree in the most striking manner, and converge irresistibly towards the same conclusion. In the first place it has been noticed for a long time that the number of spiral nebulæ observable is much less in the neighbourhood of the Milky Way than in the regions away from it and nearer the celestial pole.

This fact has created among astrophysicists discussions without end. I shall here only give the conclusion which is now generally admitted, and is as follows : that if the spiral nebulæ appear less

numerous in the galactic plane, this is due to the fact that they are objects external to the Milky Way and very far removed from it. The diffused matter which exists and has been observed in certain proportions among the stars, and which therefore forms clouds more abundant in the plane of the Milky Way than at the galactic poles, explains that these spiral nebulæ should be more numerous near those poles. It means that their light is less often obscured in those quarters by those absorbing clouds of cosmic dust.

A second method has led to exactly the same result. It is the study of the new stars, or as astronomers call them the *Novæ* (astronomers alone among savants have preserved the habit of Latin designations, so valuable from the international point of view). The Novæ are feeble stars which suddenly as a consequence of a prodigious cataclysm increase rapidly in brightness, attain a certain maximum, and are then extinguished or fade away slowly, presenting in their spectrum and in their photometric curve certain constant peculiarities.

It is just this constancy of their peculiarities observed in the case of all the Novæ in the Milky Way, particularly the constancy of maximum brightness attained by the Novæ, which is the same for all of them, which has enabled us to calculate in a novel manner the distances of the spiral nebulæ.

By photographic methods we have discovered in

these nebulæ a certain number of Novæ whose photometric and spectroscopic evolution is identical with that of the Novæ of the Milky Way. Therefore their maximum real brightness must be the same. Knowing their maximum apparent brightness, the distance of the spiral nebulæ of which they form a part has been deduced. The numbers obtained are in full agreement with the results of the methods previously described. They show us that the nearest spirals are at a distance of 100,000 parsecs and have dimensions analogous to those of the Milky Way.

On the other hand, an examination of the spectra of the spiral nebulæ shows that they consist of stars, though even with the most powerful instruments no one has ever succeeded in resolving them into their components. This is quite natural in view of their distance, which is incomparably superior to that of the star-clusters. Indeed the same conclusion is reached by a study of the superficial brightness of these nebulæ.

From all this we may conclude, in a manner which seems inevitable to most astronomers, that the spiral nebulæ are stellar systems comparable to our Milky Way, and that each is made like the latter of thousands of millions of stars. As to the distance of these nebulæ the figures indicate that it is over a million parsecs in most cases.

At a low estimate it will take 8,000,000 to 10,000,000 years for light to reach us from some of them which we can see in the telescope. These numbers are, on the other hand, quite compatible with the radius of curvature of the finite universe as conceived by Einstein, this radius being, according to Einstein's calculations, over 150,000,000 light-years, as we shall see.

The distance of these nebulæ is on the average 100 times greater than that of the star-clusters whose distance astounded us a little while ago.

Light, in short, which reaches us from certain spiral nebulæ, and which darts through space at the rate of some 186,000 miles per second, takes several million years to reach us. The time taken by light to reach us from those distant universes is counted by tens of thousands of centuries.

Thus the cosmos as revealed by present-day means, which are very inferior no doubt to those of to-morrow, seems to be formed by a million stellar systems as vast as our Milky Way, and separated by oceans of uninhabited void which light, in spite of its mad velocity, takes thousands of centuries to travel. Is not this image of the universe grand and overwhelming?—this image shown us by dry science—science which does not dream, but deals with facts? There are statements of facts which are more dazzling and fairy-like than any dreams, for our imagination

is a very poor climber in comparison with the sublime reality.

. . . . .

And yet, and yet—to conceal nothing, I must acknowledge that this conception, so attractive and yet so convincing, which considers spiral nebulæ as galactic universes similar to our own, has lately been severely damaged by researches which have made a deep impression.

It is like this. Spectroscopic study of the spiral nebulæ has revealed considerable radial velocities, amounting on the average to 500 or 600 miles a second. Most of these radial velocities are speeds of increasing distance. The greatest speed observed is that of the nebulæ N. G. C. 584, which moves away from us at a speed of 1,100 miles per second, or 4,000,000 miles in the hour. It is the greatest speed observed among the heavenly bodies.

It is 1,500 times greater than that of the projectile of Big Bertha. What in comparison are the poor 47,000 miles per hour of the sun, carrying along in its rays its little parasitic planets, like fleas in the mane of a lion? But however enormous it is, that great speed is still far behind the wall, the insurmountable limit, the universal record, which nothing, not even the cathode particle, will ever surpass, the 700,000,000 miles an hour of light. One must learn to be satisfied with little. If the spiral nebulæ were

nearer to us these prodigious displacements would eventually change their apparent shape. But nothing of the kind is shown on the photographs taken at intervals of 15 or 20 years.

On the other hand, we are told that things are different when we study the rotation of some of these bodies.

In placing side by side on the centre of the spectroscope the opposite ends of certain spiral nebulæ which we see in section, it is found that the spectrum lines at those ends do not always coincide. From such a displacement we can easily deduce by the Doppler-Fizeau principle explained above the linear speed of rotation of the opposite ends of the nebulæ.

This speed has been measured at a certain distance from the centre in the case of several nebulæ. Mr. van Maanen, of the Mount Wilson Observatory, announces on the other hand that in certain nebula photographs taken at intervals of several years, he has traced slight displacements of the spires. It is natural to suppose that the amount of these photographic displacements corresponds to the measured radial velocities of rotation. These photographic displacements indicate, for example, in the case of the nebula M. 101 that it makes a complete revolution in 85,000 years. But as it is observed that at a given distance from the centre its radial velocity of rotation

is 200 miles a second, we can easily find this distance from the centre in miles, and also the distance of the nebula. Now it is found that the nebula is only 25,000 light-years away from the earth, that is to say, incomparably nearer than the distance attributed to spiral nebulæ in general.

If that is so then we have a choice of two things: (1) Either it is proved that the photographic displacements announced by Mr. van Maanen are not real, but are due to the progressive contraction of the photographic emulsion or brought about by some other disturbing cause unconnected with the nebula observed; in that case the grand conception of isolated universes similar to the Milky Way remains intact; (2) or the displacements announced by Mr. van Maanen are confirmed and we are obliged to conclude that some at least, if not all the spiral nebulæ, are bodies much less vast and much nearer than we had believed. Yet this last conception would still give rise to a mass of contradictions and difficulties. One cannot reconcile it either with the spectrum of the spiral nebulæ or with the phenomena shown by Novæ.

In the second case the observable universe does not surpass some 100,000 light-years in extent. On this hypothesis it consists entirely of the Milky Way and its annexes. In the former case it is at least 10 times and probably 100 times more vast. It is

formed of millions of stellar islands similar to our galactic system. It is the hypothesis of Island Universes.

It has recently become clear that the emotion first caused by the results of Mr. van Maanen were not well founded. M. Knut Lundmark has just announced that measurements made on these nebulæ and on other negatives taken at intervals of 25 years, show no signs of rotation. Mr. van Maanen must therefore have been deceived by some source of error.

Finally, if we consider the radial velocities which increase or diminish the distances between us and these nebulæ, we are led to a conclusion which completely excludes the result which Mr. van Maanen felt justified in announcing. These bodies move away from us or towards us with speeds of from 500 to 600 miles per second. Their displacements in a lateral direction must therefore be of the same order as in the case of the stars. Moving along the celestial sphere they must therefore produce a displacement of this nebulæ among the neighbouring stars. Now the most delicate and numerous measurements made in this direction prove that there is no sensible apparent effect, and that if it exists at all it is certainly less than 4 seconds of arc per century, or 0·04 seconds of arc per year.

From this we can easily calculate a minimum value of the distances of these spiral nebulæ. Thisminimum

value is quite compatible with the hypothesis of Island Universes, and is nearly ten times greater than the numbers deduced by Mr. van Maanen from the displacements shown on his photographs. All this tends irresistibly to prove that the latter are due to accidental causes, and that the conception of Island Universes is no longer in any danger from its rivals.

I am in any case disposed to give the benefit of the doubt to the first of these hypotheses. Firstly, because the scientific arguments in its favour are stronger and more numerous, and objections to it are more easily met. Secondly, because it is more fascinating, more dominating, more suitable for mystic dreams, and full of overwhelming grandeur. It allows us to think that the light which now comes to us from the nebula of Andromeda departed from it before the first Pleistocene glacial period. Thus we now perceive the nearest spiral nebulæ as they were when the dinosaurus still reigned on earth.

The history of astronomy shows that its conceptions have always evolved towards a universe expanding in time and in space. And thus, if we have an option, let us choose the greater.

CHAPTER V

THE LIFE AND DEATH OF STARS

Genesis of suns—Chemical unity of the universe—The temperatures of the stars—Their real brightness—Giant stars and dwarf stars—Stellar diameters and interference fringes—Spiral groups—The death of the universe.

FONTENELLE tells somewhere the history of a family of roses each one of which lived only for a day, and having in this short time observed no change in the face of their gardener they transmitted to each other the hereditary idea that it was eternal.

For a long time men were similar to these roses with regard to their sky. I ask pardon for the comparison! Since for some 50 little centuries of history the aspect of the constellations hardly changed they believed in their simplicity that the stars were the very symbol of changelessness, and on that account they were called fixed. We know now that these stars—and our sun among the least considerable of them—are, like all nature, susceptible to the judgment of time, and that they are born, live, and die in humble submission to the prevailing laws of evolution.

Although the entire duration of thinking humanity is only a flash in the life of the stars, the heavens show us at the same time all these successive phases.

In those immense gardens in which the stars are the bright and various flowers, we resemble the naturalist who, in walking through the forest, observes oaks of different ages and surveys in one instant the secular cycle of their existence.

We know that those oases of light which the telescope discovers in the deserts of space, and which are called nebulæ, are the breeding-grounds where future suns are born, and in this case I refer to the nebulæ which cannot be resolved and which the spectroscope shows to be gaseous, as distinct from the spiral nebulæ.

Long ago there existed serious people who supposed that the nebulæ were holes in the celestial vault through which we could see the light of the Empyrean. But appearances deceived them, which only happens too often on the terrestrial globe, whether we use the telescope or not. And although in conformity with the Apocalypse, that opinion was erroneous.

Here and at every step made in astronomy, reality has been a hundred times more marvellous than fable. It has shown that many nebulæ are heaps of phosphorescent gases whose extent and state of rarefaction confound the imagination, and which are disseminated widely through the Milky Way. The beautiful nebula of the constellation of Orion, which in winter passes the meridian towards midnight, and whose fantastic form resembles an eagle with

spreading wings, is one of the most remarkable of prototypes.

It is a strange circumstance that the spectroscope only shows three gases in the nebulæ: nebulium, which is still unknown on earth, hydrogen, and helium. Many ingenious and uncertain hypotheses have been built on this. Can it be because at the extremely low temperature, near the absolute zero, which many people suppose to reign among nebulæ, only those bodies which are most difficult to liquefy, i.e. hydrogen and helium, can exist in considerable quantity in the gaseous state? Is it because the heavier atoms do not exist there, and will not be formed until later in the course of gravitational condensation? Is it because these heavy atoms do exist in the nebulæ, but are drawn to the centre of gravitation and that we only receive light from the external parts? Who knows? As regards the origin of the nebula light, we have been led for several years to attribute it to Hertzian waves emitted by the stars which cross space in other directions, and which are known to have the property of illuminating rarefied gases.

We can now imagine the mechanism, first conceived by Laplace, and hardly changed by his successors, which produces stars from that sidereal protoplasm represented by the nebulæ. The nebular gases are gradually condensed towards the centre by the

natural attraction of their particles. It is the movement due to this condensation which automatically produces the enormous heat we find in the stars. It has been calculated that the total heat thus produced by the nebula which gave rise to our planetary system since the remote age when it extended as far as the orbit of Neptune would have sufficed to keep up for 18,000,000 years the formidable radiation of the sun at its present rate.

When the density of the star thus formed becomes too great to allow the work of condensation to proceed, its temperature falls until it ceases to radiate any light and the star floats freezing and invisible in space, while other nebulæ give rise to other suns.

By placing in front of the object-glass of a telescope a prism which covers it, we obtain at the focus of the instrument a spectrum of the star. In this small luminous band, showing all the rainbow colours into which the spectroscope draws out white light, small black lines indicate by their position the various chemical elements of the star.

The first result of spectrum analysis of the stars has been to show that the same elements are found at the farthest ends of the universe. One could have been led to believe that the chemical elements found on earth are the products of some local circumstance. It might have been supposed that in other parts of the sky matter took upon itself different

forms, just as animal species vary from one region of the globe to another. The spectroscope has shown that that is not the case, and that the same atomic structures exist from one end of the universe to the other. Thus the material unity of the world was brilliantly confirmed.

A simple thrill of the ether detected in the spectroscope shows us how the subtle atoms vibrate in distant suns on the frontiers of the cosmos.

Yet in comparing the spectra of a large number of stars differences are found between them. In certain white stars, like those of the radiant constellation of Orion, the wintry ornament of the night, the metallic lines are distant or barely visible. Their spectrum is only crossed by a small number of black lines, those which indicate hydrogen and helium.

One should remember in this connection that this last gas was discovered in the sun's atmosphere by Lockyer in 1869, 26 years before being found on earth. Hence its name. Thus in the sun, 93,000,000 miles away, there was discovered a new substance a quarter of a century before it was known in the air which we breathe! Since the discovery of Neptune by Leverrier, no more striking proof of the power of astronomical methods has been obtained.

In another group of stars which comprises Sirius, the twinkling queen of our winter nights, and Vega, the chief star of the celestial lyre, the lines of helium

are feebler, while those of hydrogen are stronger. This seems to indicate that the latter gas is the chief component of the atmosphere of these stars; the metallic rays are much more numerous and they are also much more intense than in the stars of the preceding group.

In another series of stars which contains Arcturus, the flaming eye of the ox-driver, Capella of the Goat, and our own sun, the lines of the metals, notably of iron and titanium, are strong and abundant. Finally, there exists a last spectroscopic category. It includes the stars of red colour, like Alpha of Hercules, and like Antares, where the metallic lines are still more marked. Besides the lines belonging to these chemical elements, which are all found in this group of stars, there are also lines belonging to compounds, notably certain metallic oxides and cyanogen.

To sum up, as we pass from the stars of the Orion type to the cyanogen stars, the number and complexity of spectrum lines, that is, the chemical bodies shown by the spectrum, increases. This shows the presence of heavier and heavier metals, until finally at the bottom of the stellar scale we get the heavy and complex molecules of chemical compounds.

The great British astrophysicist, Sir Norman Lockyer, was the first to explain these various peculiarities of the different temperatures which exist among the stars. By experiments which have since

become classical, he showed that the spectrum of the same body presented characteristic variations when placed in succession in a flame, in an electric arc, and finally in an electric spark, which, as we know, constitute hotter and hotter sources.

From the fact that the same metal can, according to the temperature, emit either the lines shown in the electric arc, or those enhanced lines which are observed at the higher temperature of the electric spark, Lockyer concluded with rare boldness that at high temperatures chemical bodies must be dissociated into simpler chemical elements, which he calls proto-elements.

The recent work of Saha tends to show that certain lines of the elements disappear when their atoms are strongly ionised, as a result of a high temperature, i.e., when they shed their external electrons. These new views justify and clear up those of Lockyer. The discoveries brought about by radio-activity have given a great probability to Lockyer's theoretical views, which were at his time considered chimerical by many. His was a recent epoch, it is true, but it was governed by the dogma of the immutability of the chemical species.

In short, assuming a bold parallelism between the radiations of spectra observed in the laboratory in the hottest fires, and those observed in the stars, Lockyer concluded that the spectrum differences of

the latter are due to their different temperatures. Then the radiation of the stars can be considered as follows: since the cosmogonic hypotheses of Laplace, Kant, and their successors have been put forward we have had powerful reasons to suppose that every star is formed by the progressive condensation of matter originally diffused in space. Whether this matter is gaseous, as assumed by Laplace, or whether it exists in clouds, in particles, or meteoric dust, as Lockyer supposed, the result is the same: under the influence of gravitation, which gradually condenses this matter, a rise of temperature is produced by the more and more frequent collision of the particles or molecules that compose it. A star heats up as it condenses.

But as we have said, there is a limit to this heat indicated by calculation. The density and viscosity of the stellar masses as they grow by condensation tend to slow it down. When we inflate a tyre, with the constant exertion the concentration of air first increases very fast, and then more slowly. So there arrives a moment when the heat produced by the work of condensation becomes less than the heat of the star by radiation into space. The star therefore passes through a maximum of temperature and then starts cooling down towards its final extinction.

From the chemical point of view, and also from the spectroscopic point of view (this is one of the boldest peculiarities of this conception, which has been corro-

borated by recent work) this elevation to a maximum and this diminution of the temperature of the star is, according to Lockyer, accompanied by a sort of progressive transmutation of its chemical elements. Heating first changes the heavier atoms into lighter ones and dissociates them. Afterwards the progressive cooling of the star produces the former at the expense of the latter. Recent calculations of Saha on ionisation in the stellar atmospheres do not rule out this view.

In the hottest stars, including hydrogen and helium stars, would the heaviest chemical elements be dissociated and changed into gases? We should then have to admit that when, in the course of ages, a star cools and slowly passes from the Sirius type to the solar type, hydrogen gradually forms the other metals by condensation. Thus the stars would furnish us a striking example of that transmutation of the elements which has been the dream of alchemists since the Middle Ages.

The changing of lighter atoms into heavier atoms, of common elements into precious elements, that dream of alchemy, would thus be a reality at the temperatures and pressures which exist in the stars. Why should it not be realised on earth? It is a question which we cannot answer to-day, but many similar ones will be answered in the next few centuries.

The light of a star can be compared with that of a living being which first arises in power and ardent beauty, then declines and returns to the original nothing at the end of its life.

But let it be distinctly understood that I exclude from this comparison the beings which have the privilege of an immortal soul. The "nothing" of which I speak in this case is but the molecular disintegration and annihilation of that perishable edifice which gives to an organism its individuality. Thus a serpent biting his own tail is an ancient symbol not only of organised life, but of the life of suns, which are as perishable as ourselves in the plane of infinity.

Some among the stars must therefore be rising in temperature while others are in the falling phase of their thermal power. Sir Norman Lockyer, starting from the spectroscopic views of the various stars, has been led to classify them in a certain number of groups which he arranges in a curve.

This curve shows to some extent the shape of a jet of water which rises and then falls back, and the hottest stars are at the top of the curve. On one side are the stars which are heating, and on the other side are those which are cooling down. On both sides some are found at the same height passing each other, either in the ascending branch, or in the descending branch of the curve. It follows that among the stars which have a given temperature some are still heating

up, while others are cooling down. This is just what recent discoveries have proved, as we shall see.

All the views set forth above lacked instrumental confirmation. What was lacking was a method of determining really and numerically the temperatures of the stars, and comparing them with the conclusions of theory.

This gap has been recently filled, and the measurement of stellar temperatures constitutes one of the recent results of astrophysics. The first method utilised in this connection has been carried out by us at the Paris Observatory. It consists in placing beside the star whose temperature is to be measured, in the focus of the telescope, a small artificial star optically produced by means of an electric lamp, the filament of which has a known temperature and brightness. The brightness of the artificial star can be varied by means of Nicol prisms, until it is equal in brightness to the real star. This equality is produced several times in succession by interposing between the eye and the two stars different colour-screens combined chemically, which only transmit such and such a portion of the visible spectrum of the two stars.

It is clear that the measurements thus made give us the quantity of distributions of intensity in the spectrum of the real star. Now this distribution is linked to the temperature of the star by the well-

known laws of monochromatic radiation summarised in the celebrated formula of Planck.

This formula expresses numerically the well-known fact that the colour of any incandescent body, solid or liquid, which is red at first, becomes whiter and whiter as the temperature rises.

In the absence of simpler words, we have called the apparatus constructed on this principle and used in the Paris Observatory, a "heterochromic stellar photometer." It was standardised with electric furnaces at various high temperatures. Applied to the sun it indicated an effective temperature of about 5,300° centigrade, a number which closely agrees with that obtained by the ordinary methods. This agreement establishes the validity of the new method.

As regards the various classes of stars, the apparatus furnished the following results, which can now be considered as established, since they have been confirmed in the various European and American observatories.

The helium stars have effective temperatures which on the average amount to 15,000°. Certain stars of this type have a rather low temperature, like Algol, with its 13,000°, but they reach 22,000° with Gamma Pegasi, and 28,000 in Zeta Persei. Those are the hottest temperatures observed in nature.

The hydrogen stars are rather less hot on the average. Sirius, for instance, has an effective temperature of about 12,000°, which is still a good deal.

We can calculate that, if our kind sun were as hot as Sirius, the average temperature of the earth would, all other things being equal, be above 110° centigrade, and no human or animal life would be possible.

The temperature which is now found in Sirius was formerly possessed by the sun before the icy hand of age had made it a decrepit and wizened old man among the stars. At that time, however, no trace of life existed down here. From the point of view of time, as of space, the temperatures compatible with life are only a thin line in the infinite plane of possibilities, and in the finite though immense plane of realities. The thermal evolution of the stars emphasises the narrowness of that brief parenthesis constituted by life in the romance of the skies.

Below the hydrogen and helium stars come others like the Pole-star, which have a temperature of about 8,000°. Then follow, still lower down, the stars resembling the sun, like Arcturus, or Capella, their temperatures varying from 4,000° to 6,000°. Finally, after Aldebaran, the red eye of the Bull, with 3,500°, there come quite at the bottom of the curve stars like Betelgeuse, like Rho Persei, or like the star No. 19 of the constellation of the Fisher, most of whom only indicate 2,000°. They are considerably cooler than many of our flames and much less hot than the positive crater of the electric arc.

In general the numbers observed roughly follow the order which Lockyer had foreseen from his spectrum analysis. Still there are differences which occasionally are very noticeable. But it must not surprise us. The thermal classification of stars according to their spectra depends on the temperature at the surface of their photosphere. On the other hand, the effective temperature which is determined by heterochromic photometry depends upon the radiation emitted by the star after traversing its more or less absorbing atmosphere. By comparing the results of the two methods we have been able to obtain new data concerning the mass of the atmospheres which surround these stars. That is not all. A numerical knowledge of the effective temperatures of the stars enables us to calculate the approximate quantity of light emitted by each per unit of surface. There exist well-established numerical relations between the effective temperature of an incandescent body and the total light which it emits. It has been proved that every square centimetre of the surface of the star Rho Persei emits at the most one-tenth of the corresponding light radiated by the sun, and which is equivalent to 320,000 decimal candles. On the other hand, Vega is equivalent to more than 6,000,000 candles per square centimetre.

Finally, knowing its parallax, its apparent brightness, and its luminous emission per unit surface, we

can immediately calculate the diameter of the star. This has been done, and the results obtained have been strange in many respects.

Sirius, that queen of the stellar firmament, whose matchless light has so often haunted poets and philosophers, Sirius which on account of its real brightness, greatly superior to that of the sun, was believed to be a giant star, has a diameter barely exceeding that of the sun, and certainly not as much as $1\frac{1}{2}$ times the latter. It is quite the opposite in the case of Aldebaran, which, in spite of its brightness, has a diameter 13 times that of the sun, and therefore a volume 2,000 times greater.

These are some of the suggestive results which have been obtained by measurements of stellar temperatures made possible in recent times. We shall see how they have been confirmed and extended by entirely independent experiments carried out by Michelson.

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Before these experiments we had no means of directly measuring the diameter of the stars on account of their almost fantastic distances. The nearest of them, if it had the same dimensions as the sun, would only have an apparent diameter equal to that of a marble one centimetre thick, seen from a distance of 200 miles. In the focus of the most powerful telescope it would give an image less than

the small luminous disc produced by a distant point having no dimensions at all. The spreading out of this disc is due to the diffraction of the enormous rays of the edges of the object-glass. The disturbing influence of that edge, the diffraction which it produces, is more important the smaller the object-glass. That is why the small patch which constitutes the image of a star is greater when its light is brighter. That is why the stars appear thicker although less luminous by the naked eye than by a telescope. Yet there exists a means of getting over these difficulties, indicated some time ago by a profound remark of Fizeau. It is founded on that curious phenomenon of interferences which we may learn to visualise by means of the waves produced by the fall of a pebble in water.

Some story-writers describe a perfectly idle person, both materially and morally, whose lazy brain only produces most unformed thoughts, as drawing circles in water. Such an occupation is characteristic of a sort of intellectual lethargy which seizes all of us during certain hours of idleness.

It should not be so. To tell the truth I hardly know a spectacle more suggestive, more capable of awakening dormant thought, more astonishing, richer in information, more marvellous and suggestive, more richly charged with ideas and striking images than a circle produced in water by the falling of a pebble.

These circles, which expand with a slow and continuous movement and a uniform speed, like circular wrinkles which animate for a moment the calm face of the water, which arise and disappear round their centre and pass along to the border where they disappear, which evoke the ephemeral and yet eternal destiny of all that which is born, grows, and dies, represent all life with its expanding and swiftly decaying flowers.

But the circles made in water do not only give rise to flowery, philosophical thoughts full of literary melancholy; if they did, they would not be in my province. They also evoke, with surprising precision and accuracy, all the undulating vibrations which fill the world, especially those of joyous, subtle, and marvellous light, a liaison agent between our hearts and the vast universe. In particular they enable us to comprehend interference fringes.

Let us examine the two systems of waves produced by the fall of two pebbles thrown at the same instant into the water a foot or two away from each other. We notice that the two distinct groups of mobile undulations get entangled with each other and produce on the surface of the water a series of immobile waves which we may call stationary waves. The crests and troughs of these stationary waves correspond to the points where the crossing waves intersect in their crests or their troughs,—in other words, in

identical phases. These crests and troughs reinforce each other at the point of intersection. At that point we have thus a wave which rises and falls in its place, a stationary wave. That is the phenomenon of interference.

Similarly two luminous rays which cross in certain conditions in a point to which they converge, produce in it a series of alternate maxima and minima of light. The maxima are in the place where the waves of two rays are in the same sense and reinforce each other; the minima are at the neighbouring points where there is a small difference between the distances traversed by the two rays, so that the waves oppose each other and produce darkness. One therefore sees an alternate series of maxima and minima of light. These are the interference fringes.

Now here is an astonishing suggestion put forward by Fizeau about fifty years ago:

"There exists through most of the interference phenomena a remarkable and necessary relation between the dimensions of the fringes and the size of the luminous source, such, that fringes of extreme fineness can only be produced when the luminous source is of a size too small to be appreciable. We may also remark in passing that here is perhaps a hope that by basing ourselves on this principle and by forming, for instance, by means of wide slits far apart, interference fringes in the focus of the great

instruments designed for observing the stars, it would be possible to obtain new data concerning the angular diameter of the stars."

That is the idea of Michelson as just applied with great ingenuity by means of the most powerful telescope in the world, that of Mount Wilson, the mirror of which is 100 in. in diameter. In placing in front of this instrument a diaphragm having two slits some distance apart, each of these is made to isolate a thin luminous beam emitted by the star observed. The two beams converge in the focus of the telescope and form interference fringes parallel to the slits. When the latter are a certain distance apart the fringes disappear. Calculation shows that there is then a simple relation between this separating of the slits and the apparent diameter of the star, which thus results from the observation.

The first star to which this method was applied was the red star, Betelgeuse, which, like a ruby, constitutes the upper clasp of the twinkling shoulder-strap of Orion, the Divine Huntsman, changed in the olden times by Diana into a celestial star figure. It has thus been found that Betelgeuse has an apparent diameter of 46,000ths of a second of arc.

Taking its distance into account we may conclude that it possesses a real diameter equalling 214,000,000 miles, i.e. 230 times greater than the diameter of the sun. If the latter with its retinue of planets were

placed in the centre of this monster, the terrestrial orbit would be entirely enclosed within its outer surface.

These fantastic dimensions are even surpassed by the star Antares, which has been shown by the Fizeau-Michelson method to have an apparent diameter equalling 40,000ths of a second of arc. But since it is farther away from us than Betelgeuse, we find, taking that distance into account, that it corresponds to a real diameter of Antares in the neighbourhood of 400,000,000 miles.

The same process applied also to Arcturus and Aldebaran indicates diameters agreeing with those calculated by the above method on the basis of the effective temperatures of those stars.

This is a precious confirmation of that method which gives an unshakable value to the singular results to which it has led concerning the evolution of the stars themselves.

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We have seen that in contracting the stars at first rise in temperature. Then when the too advanced condensation retards this contraction they gradually cool, after attaining a maximum temperature. One and the same star therefore passes through the same temperature at two different moments: for the first time in the initial phase of its condensation, where the temperature is ascending, and a second time

during the terminal phase when its temperature falls. The first time, the star being less condensed, must be much more voluminous than the second time. On the other hand we find in the skies stars corresponding to the different stages of stellar evolution, just as in forests or in nations we find trees and men of all ages.

It follows that the stars of the same temperature must be partly very voluminous, while another portion of them must be much smaller. That is precisely what has been proved by the facts recently collected by Professor Russell, whose views on dwarf stars and giant stars are one of the most elegant acquisitions of stellar astronomy.

As a star condenses and heats up—which it does in the initial and ascending phase of its thermal evolution—the intensity of radiation which it emits per unit of surface increases, but at the same time the emitting surface decreases. We may calculate that the total luminous emission of the star hardly changes at all during the whole phase, for the diminution of its surface makes up for the increased intensity of its radiation.

Matters are quite different in the descending phase of the evolution of the star, and when the latter, having passed its highest temperature, cools down without ceasing to condense. Then the radiating surface diminishes together with the intensity of

radiation, and the total brightness of the star, instead of remaining the same, decreases rapidly.

That is just what recent observations have made clear. Let us classify the stars according to their spectra, taking into account their absolute magnitude, i.e. real brightness, supposing them to be placed at the same distance from us. These absolute magnitudes—that of the sun being defined as five—group themselves with each spectrum type round two mean values. One of them is a high value which is nearly constant and equals 1·2. The other is feeble and advances regularly from 4 to 11 in passing from the whitish stars to the red stars. In other words, if the sun is a star of the 5th magnitude, at the distance where we have placed it in company with the other stars, it is found that there are two kinds of stars for each spectral type. One kind comprises very bright stars of about the 1st magnitude, and all are very much the same brightness. The others are much less bright, ranging from the 4th to the 11th magnitude, and they are fainter as they get redder. The former are the giant stars, enormous suns whose brightness varies very little; they are still vast but slowly condensing; the others are the dwarf stars whose state of condensation is already very advanced. Our insignificant sun belongs to this last category. It verges on its final decrepitude; its moments, or rather its thousands of centuries, are numbered.

Sirius is also a dwarf star, like Procyon and 61 Cygni, one of our near neighbours, and that curious Proxima of which we have spoken. On the other hand, Mu Geminorum, Regulus, and Beta Andromedæ are twinkling examples of giant stars. The declining position of the sun in the family or category of stars is not only proved by what we have said, but also and particularly by its mean density. It is equal to nearly one and a half times that of water and corresponds to a considerable degree of condensation. This follows clearly from calculation, as shown by Homer Lane and Eddington in their beautiful research on stellar dimensions.

There is indeed no secret, however hidden, which calculation, armed with the instrumental results of modern physics, does not dare to investigate. It does not hesitate to inquire what must and should be the physical conditions obtaining not only at the surface of stars—where we have optical, photometric, and spectroscopic means of control—but even in the interior of the stars and down to their centre. The results attained by Eddington in this matter cannot claim a rigid accuracy. But they are none the less probable as far as their order of magnitude is concerned, and they infinitely surpass, in the gigantic facts dealt with, all that we are accustomed to in our little laboratory experiments.

If we calculate the distribution of temperature in

a star of mass equal to that of the sun, but whose condensation is a little more advanced, so that we can correctly apply the laws of gases, we find that at the centre of such a star the temperature must be about 5,000,000° and the pressure 21,000,000 atmospheres.

We can hardly imagine the state of matter in such conditions. It is quite possible that the pressures obtaining at the centre of the star suffice to condense the light atoms into heavier atoms, and especially to create radio-active substances. These would therefore be constantly regenerated in the interior of the stars, and would contribute to prolong their heat.

Calculations also show very clearly that all the stars do not in the course of their evolution attain the maximum temperature.

At the climax of their careers, only those attain the high superficial temperatures measured at the Paris Observatory, surpassing 15,000 to 20,000°, which belong to the Orion type and have a gigantic mass. It has been calculated that to obtain the temperature of the helium stars it is necessary to have a mass at least seven times greater than that of the sun. The climax of the stars of mass equal to that of the sun is not higher than that of Sirius or Vega, which remain below 200,000°. Probably the sun has never exceeded that superficial temperature,

even in the ancient times when it shone with all its brightness. Where were we then? "What did we in those torrid days?" Nothing at all, because if the sun suddenly reached 12,000° of effective temperature all life would be excluded.

To represent all this by an analogy, we may say that the stars have their birth, and their death, passing through a certain climax of vitality and heat, just like all the human race, between infancy and old age. This climax or maximum is not always the same. Just as the intelligences of niggers at their best is on the average inferior to that of whites.

The factor which governs the highest temperatures of the stars is, as we have seen, its mass. That is easily understood. The greater the mass, the more considerable the gravitation and consequently the more intense would be the heat produced by condensation. The fact that the heat lost by the radiation of a star is at a given temperature and pressure the greater the greater its mass, tends in the same direction. A plumber's soldering-iron or a washer-woman's smoothing-iron require heating the less often the heavier they are.

Just as there are heavy stars which must have reached a maximum temperature higher than that of the sun, so there are stars of feebler mass which have never attained and never will attain even the moderate temperature of the sun. Calculation shows

that a star less than the 7th of the solar mass never could reach a temperature of 3,000°. This explains why no visible star is known which has a mass inferior to one-tenth of the sun.

In this connection, why is it that the masses of all the stars so far determined should be of the same order of magnitude? In other words, why is it that all the stars have nearly the same size, like men or horses, and that no stars have been found which are thousands or millions of times heavier than the sun? Philosophically speaking, probability shows that all stellar masses should be possible, and the question is quite justified. It involves high speculations of stellar dynamics, studied particularly by Henri Poincaré, which show that on account of the kinetic movement of the gaseous molecules and also of centrifugal forces stellar condensation cannot pass beyond a certain limit.

More recently Eddington has made a very interesting contribution on this subject, founded upon a phenomenon which I mentioned before, the Maxwell-Bartoli pressure, or the pressure of radiation. This phenomenon consists in the fact that light and radiation in general exercise a pressure on the surfaces upon which they fall.

That being so, and knowing from experiment the value of that pressure, Eddington calculated the ratio which exists in the interior of a radiating sphere

corresponding to a star between the radiation pressure, which tends to drive the material of that sphere away, and the gravitation, which tends, on the contrary, to concentrate it. It is found that of these two forces, away from and towards the centre respectively, the former is always very inferior to the latter, so long as it is a case of masses less than that of the sun. To fix our ideas, in a mass half of that of the sun the pressure of radiation is less than the tenth part of the gravitation. But in a mass ten times superior to that of the sun the former of these is nearly equal to the latter. It follows when the concentration of matter in the space finds no conditions favourable to its growth, that the mass concentrated is much superior to that of the sun. That explains why there are no stars of immensely greater mass than the sun.

I may here recall the fact that the mass of the sun is over 330,000 times that of the earth, and represents a number of grams expressed by the figure 20 followed by 32 ciphers.

The giant stars can therefore only surpass their dwarf sisters as among ourselves giants exceed dwarfs in stature, i.e. moderately.

From the above it results that a star of equal mass will be successively a giant and a dwarf, relatively at least, at different stages of its career.

A question has recently been raised as to what

is the number of the stars at those distinct stages.

The question is not easily answered, for on account of their brightness the giant stars are visible to us at a much greater distance than the dwarf stars, so that they figure in the catalogue in a proportion which greatly exceeds their real frequency.

Thus Sir F. Dyson, the British Astronomer Royal, had concluded from an examination of the Carrington catalogue that 95 per cent. of the stars are brighter than the sun. But when we consider those whose parallax surpasses one-fifth of a second, we find 4 stars brighter than the sun against 21 which are less bright. We may conclude that in reality the dwarf stars predominate numerically, but that they are as a rule insufficiently bright to figure in our catalogues unless they are our near neighbours.

This principle means that the stars remain longer in the stage of dwarfs than in the state of giants. In other words, the phase which follows their climax is longer than that which precedes it. Their old age lasts longer than their youth. In a word, the stars are precocious beings, which after a brief morning pass a very long afternoon before their extinction.

One is led to conclude that the dwarf stars nearing extinction constitute the most numerous class in space, although we only know few of them, since at a medium distance they cease to be observable.

Extending the preceding mode of reasoning to the various stars of known parallax, the results point to the same conclusion.

All this agrees well with Russell's theory and the ideas of Lockyer. The stage at which stars are giants is comparatively short and probably only about 1 in 30 is in that stage. Besides, the climax or grand maximum characterising the stars of the Orion type requires a considerable mass, and also a stage of evolution corresponding to the highest temperature. It results from statistics that the number of stars passing through this climax is about one star in 2,500.

In short, the stars nearing the end of their career, those which have arrived at the limit of their condensation and at the extreme decline of their radiation, those which Mr. Crommelin calls the extreme dwarfs, must form an important percentage of the total number of stars, possibly three-quarters. Thus they form a much more considerable part of the stellar population than might be supposed from the astronomical catalogues prepared by the classical methods. These in fact indicate a majority of giant stars which does not correspond to reality.

If a great number of stars are near the end of their evolution, a still greater number have attained that final stage when, completely extinct and congealed, they roam through the darkness of space inaccessible

to our ordinary methods of observation. According to certain estimates which can only be approximate, it is thought that the obscure extinct stars are about a thousand times more numerous than the luminous ones. It would therefore not be between 1,000 and 2,000 stars which make up the Milky Way, our little sidereal home, but more than a billion.

There is some difficulty in admitting this result if one calculates with Poincaré the total mass of the galactic universe from the amount of the proper motions of the stars furnished by observation. The future will decide these disagreements. That is well, because it would not forgive us for leaving to it no problems for solution or for handing down to it a world lacking the attraction of the unknown.

Just as humanity is composed of more dead people than living people, the entire stellar universe seems to trail in the folds of its cold abyss many more dark stars, extinguished for ever, than radiant living stars. It is a melancholy law of the whole visible world that that which lives, which vibrates, which burns and radiates, is never more than a flash, a lightning-break in the eternal procession of sombre and dead things.

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Individually, the stars are born, develop, and die. At every epoch of the world some rise up and others go out. But the whole organism of which the stars

are the perishable cells, what happens to it? In short, is the universe destined to last for ever?

It is a question as old as humanity, which metaphysicians have discussed for centuries without ever having proved anything but their dauntless ingenuity. Science has taken up the problem since. It is a sign of the times to see it escaping from the nebulous domains of metaphysics to fall, or perhaps I should say to rise, into that of pure physics. The fate of the universe has become a question of physics, and more precisely of thermodynamics. In discussing it, men of science break lances of which the steel is forged in their laboratories and under their astronomical domes. Their discussions are even marked by a certain vivacity which is unusual in the peaceful world of physics.

It would hardly be otherwise in a matter affecting the problem of destinies, when on this subject everyone, in spite of himself and in perfect innocence, sees in the arguments of science nothing but the means of supporting the ideal which he has formed. For one may be a very scrupulous observer but none the less, alas! a man.

All the philosophers and all the savants are nearly agreed on the perpetuity of those substances which we call matter and ether, and which really appear to be only modifications of each other. *Ex nihilo nihil* is for them an axiom. The mythologies themselves

agreed in that. Genesis, for instance, teaches us that the Creator formed the world, not from nothing, but from chaos. One may conceive chaos as a state in which things were not mobile, not organised nor differentiated—for organisation results from differentiation—where there were no forces and no active energies.

And this leads us to consider the two grand principles of thermodynamics which govern all the manifestations of energy in the world, and which will take us to the very core of the question. The first principle, that of the conservation of energy, is due to Robert Mayer and Helmholtz. The second, that of the dissipation of energy, was discovered by a French genius who was long misunderstood, the engineer Sadi Carnot, and was developed by Clausius.

Everybody knows nowadays what is understood by energy and that it is the capacity which objects have of furnishing work. The principal forms under which we know it are the energy due to motion, like that of a projectile which is proportional to its mass, and to the square of its speed; heat energy, which vaporises the water of steam engines and drives them; electric energy, which can be transformed into luminous energy; and into mechanical work, as in a ventilator, etc. Finally, we may refer to chemical energy, which produces heat in a gas-burner or movement in an explosive.

These few examples show that there is a certain reversibility in the various forms of energy and that we may by suitable means transform one of them into any other.

The principle of the conservation of energy explains the experimental fact that when two forms of energy change one into the other there is a constant ratio between the quantities transformed. Thus when movement becomes heat, as when a spark flashes between two colliding stones, or when the process is reversed, as in the steam-engine, the amount of work, amounting to 770 foot-pounds, is always equivalent to the utilisation of one calorie. There are other constant ratios between the other forms of energy.

The principle of the conservation of energy dominated—one might almost say tyrannised over—the science of the nineteenth century. It was long thought that one of the necessary consequences was the eternity of the universe. Since in fact different forms of energy found in the world can be transformed indifferently into each other and their total mass remains constant, must not the world necessarily pass at intervals without end through a series of grand oscillations between chaos and harmony? The *savants* of the other century lived in an atmosphere quite adapted to encourage that view. Lavoisier had proclaimed the conservation of mass in chemical

operations. Laplace thought he could, with his array of integrals, demonstrate the stability of the solar system. He did not perceive the lack of logic in proving his case when he had in his *Exposé du système du monde* manifestly shown our system arising from a primitive nebula and then evolving without end. Fourier had extolled at the end of his powerful work on celestial mechanics a "World disposed for Order, Perpetuity, and Harmony." Henri Poincaré was not yet born, who was to show the gaps in this powerful edifice of celestial stability.

It is therefore not surprising that the first principle of thermodynamics should have convinced people for a long time of the stability of the universe, its permanence, and its *variance.*

But here comes the second principle of thermodynamics long forgotten, and long misunderstood, to revise this case which had been considered closed.

The principle of Carnot, put forward in 1824, but only understood now, implies that in any machine left to itself there is something which always and necessarily changes in the same direction, something that cannot be reversed and which is called "entropy."

My readers will pardon me for not expounding to them this prodigiously abstract conception. We can get round the difficulty by summarising Carnot's discovery as follows:

In an isolated system—that is, one which does not give out energy nor receive it from the outside—the transformation of energy cannot act in both directions. If motion can be transformed completely into heat, heat can never be entirely converted into work. There is always some portion which is dissipated internally. The efficiency of every heat engine is necessarily less than unity.

For example, a moving projectile received into a vessel full of water gives out its entire mechanical energy in the form of heat. On the other hand, we can never draw from a source of heat anything but a feeble fraction of its mechanical equivalent. Thus in steam-engines no more than 15 per cent. of the heat expended is ever transformed into work. The rest does not disappear, it is simply not utilised, but is passed into a condenser and into the atmosphere with the vapour and smoke of the engine. It is wasted energy.

We are thus led to distinguish in the energy of any given system that which can be utilised. The supreme merit of Carnot was to discover that the feeble efficiency of heat-engines is not entirely a matter of technical imperfection, but that though it can be diminished it can never be annulled, and it is a necessary condition of their working. The first principle of thermodynamics says that the total energy of any system is constant. The second

principle says that the useful energy diminishes. There is here no contradiction.

Therefore, the whole motion can be transformed into heat and only a fraction of the latter into motion. A material system abandoned to itself must tend towards a final state where all visible motion and also all difference of temperature will have disappeared to give place to a uniform heat and complete immobility. That is the fate of a universe considered as an isolated system.,

Now without movement and without inequalities of temperature there is neither life nor radiation. Phenomena only result from differences, from lack of equilibrium, so to speak, just as life only comes from differentiation. A stagnant pool is a thing mechanically non-existent, even though it contain thousands of tons of water. On the other hand, the smallest brook, on account of the difference of level which makes it flow, is a living and useful thing. If I raise to the same temperature of several hundred degrees every part of a steam engine, it will not go for all that. What makes it go is the difference of temperature between its various parts.

And here comes the antithesis which confronts a doctrine established on the first principle of thermodynamics: If we can extend Carnot's principle to the whole universe, the latter necessarily tends towards a sort of thermal death—it is difficult to trans-

late the *Wärmetod* of Clausius otherwise—which would fix it irrevocably in a dull and corpse-like immobility.

Without going further and examining various objections which these conclusions of cosmic thermodynamics have raised, I must make a necessary remark, though I risk cooling certain misdirected enthusiasms. The belief in the perpetuity of the universe has, according to circumstance, been invoked for the support of quite opposing philosophical ideas. Just now it is the materialist philosophers, the monistic disciples of Haeckel, who believe in the perpetual round of things, a world constantly reformed and repairing by itself the defects we discover in it. The idea of a perishable world would imply that it had been created, which they will not admit. On the other hand, in the seventeenth century it was argued by Descartes and others that only immortality of matter and motion in the universe can harmonise with the eternity of the Creator. Thus the same arguments have served on both sides of the barricade. Let us leave these childish quarrels. It is a little ridiculous that every conquest of science has been used at once as a mental projectile which hot-heads fling at each other with great energy. It is lowering the austere search for truth if we only see in it a defence or a flaming sabre according to everybody's fancy.

Among astrophysicists who find some difficulty in

admitting the death of the universe as implied by Carnot's principle, M. Arrhenius is undoubtedly the one who has furnished the most original objections. Poincaré ascribes genius to them. In any case, they are worthy of examination.

We know that heat naturally tends by itself to pass from hot bodies to colder bodies either by conduction or by radiation. On the other hand, heat *never* passes naturally from a cold object to a hot object. That is why equilibrium of temperature finally establishes itself between unequally hot bodies placed in the same enclosure. And that is what Carnot's principle maintains.

In the stellar universe the sun and the stars gradually transfer their heat across space, and it goes to heat up the distant and cold nebulæ. It thus seems that the levelling of the temperatures, together with that of quantities of matter, tends to establish in the universe the *Wärmetod* of Clausius.

Now Arrhenius is of an opposite opinion and for this reason :

The great English physicist, Maxwell, who, in creating the electro-magnetic theory of light, showed the identity of light and electricity and heralded the discovery of Hertzian waves, imagines a case in which phenomena take place contrary to the principle of Carnot, thanks to an artifice which is now famous under the name of "Maxwell's demons." We know

that according to the kinetic theory of gases, which is one of the surest conquests of physics, a gaseous mass consists of molecules that rush in every direction with great speed, the speeds being different on account of collisions. It may be compared to a swarm of bees, where the bees represent the molecules. If this gaseous mass is heated the average velocity of the molecules increases. Now let us suppose a given vessel filled with a gas of the same temperature throughout. Let us divide it in two by means of a screen pierced with quite small holes, such that only a single molecule can pass at a time. Each hole is provided with a valve behind which there lurks an infinitely small intelligent being which Maxwell calls a demon, and Henri Poincaré a Customs officer (the latter word is more fitting, and less absurd in this fantastic fiction). The gaseous masses of the two halves of the vessel are continually stirred up and mixed by the molecules which pass through the holes from one compartment to the other. Every time that one of the little demons sees a molecule coming at high speed from the left to the right of the vessel it will open its valve and let it pass. It will close it, on the other hand, to a molecule of low speed going in the same direction. It will also allow a low-speed molecule to go from right to left, but will close the passage to high speed molecules going in the same direction.

It will soon happen that the swift molecules are united in one of the compartments and the slow ones in the other. In other words, heat (because that is what the speed of the molecules amounts to) will pass from one of the compartments which will perpetually cool down, to the other which is perpetually heating up. Heat passes from a cold body to a hotter body. We shall have divided the original isothermal gas into two fractions with different temperatures. We shall have violated and evaded the principle of Carnot.

This marvellous history of Maxwell's little demons is not believed by Arrhenius to be realised in nature. But he gives us reasons to believe that something of the kind happens.

For greater clearness I may perhaps be allowed a slight digression in connection with the gases which constitute the atmospheres of the planets. We know that when a projectile is shot by a fire-arm it takes the longer to fall back upon the ground the greater its initial velocity. There is even a speed at which a projectile would be shot so far into space that it would completely escape the gravitational attraction of the earth and would not fall back upon it. That was the case with the imaginary cannon-ball in which Jules Verne transported his passengers, and with them our youthful imaginations, from the earth to the moon.

The case is the same with the molecules which are found in the outer regions of the atmospheres of stars. It can be calculated that the molecules possessing a certain minimum speed—which is 7 miles per second in the case of our globe—escape from attraction and continue their flight towards infinity. The atmosphere thus continually loses gaseous molecules which have a sufficient speed. Since the distribution of molecular speeds obeys the law of statistics, there are always molecules with high temperatures. Therefore the atmosphere of the heavenly bodies will continually decrease. The diminution will be the greater the less the mass of the stars, for a large planet retains by its gravitation more of its atmospheric molecules than a small one. That is why the moon with its feeble mass has lost all its original atmosphere. The earth has lost hydrogen, which is very light, and nearly all its helium, while these two gases are still very abundant around our enormous sun. The earth has preserved its oxygen and nitrogen, which are heavier.

This phenomenon according to Arrhenius plays an important part in the nebulæ, where gravitation, especially at the edges, is very feeble, and the gases of which have a feeble density. The outside regions of the nebulæ will therefore easily lose gaseous molecules and will thus cool the layers away from the centre. For the same reason the heat sent from the

stars to the nebulæ does not warm them. Their radiation does communicate speed to certain molecules, but these will leave the nebulæ for ever and will be finally absorbed by a sun and will contribute to the upkeep of its radiation.

In the last course of lectures but one which he held at the Sorbonne, Henri Poincaré gave a fine analysis of these ideas of Arrhenius. He raised certain objections, but although he believed in the general truth of Carnot's principle, he seems to have been influenced by those ideas. His conclusion is prudent and hesitating, although one feels his inclination through it: "I do not wish to draw any definite conclusions from this discussion; it seems that by this process the thermal death of the universe will be enormously retarded, but we may believe that it will only be retarded."

The German astronomer, Seeliger, has tackled the problem from quite a different point of view.

We have seen from the preceding example—not to mention Maxwell's fantastic demons—that we can imagine phenomena contrary to Carnot's principle, in which heat passes from a cold body to a hot body without any compensating work. If this principle is ever defied, why should such exceptions be limited in space and in time? Can they not have important manifestations in both? These objections have been considered so strong that a new view of Carnot's

principle has arisen which considers it only a theorem of the calculus of probabilities. This principle is somewhat as follows: the phenomena which are usually produced in nature take place in a way which corresponds to a loss of useful energy.

This statistical conception still allows the possibility of natural processes which do not obey Carnot's principle. The question whether a natural law rules without exception is definitely negatived when it is considered as a theorem in the calculus of probabilities.

Another thing. The calculus of probabilities does not apply to any but fortuitous phenomena—I mean those which are produced without any apparent rule or order. Carnot's principle is of great value in many parts of physics. But who would dare to say that the movements observed in the whole universe are disordered, and that the latter evolves towards an increasing irregularity? It would be just as easy to sustain the contrary, and so the validity of Carnot's principle would become more and more feeble.

There is another argument which applies to the consequences of both thermodynamic principles: these principles can only be rigorously applied to limited systems. Before extending them to the universe we must be sure that it is not infinite. How can we speak of the energy and entropy of an infinite

system? These expressions have no meaning. The extrapolation into infinity of the small data of our laboratories is not only unjustifiable but meaningless. What meaning can there be in the words "total energy" or "useful energy" of the universe if it is unlimited?

These difficulties have, however, not discouraged on either hand certain builders of systems. They ought to have warned both those who proclaimed with confidence the permanence of the world, and the eternal cycle of things, and those who proclaimed the impending and necessary death of the cosmos. The cosmological idea of Einstein, according to which the universe is finite, tends to furnish an argument to the latter. But then they are confronted by a very embarrassing question. If the universe progresses constantly in the same direction according to Carnot's principle, if temperatures tend to become equal and motion tends to disappear, how is it that the thermal death of the universe has not yet come about after the enormous lapse of time during which it has existed?

The answer will be that the universe has not existed from all eternity. This cannot be reconciled with the first principle of thermodynamics unless all existing energy had suddenly arisen at the moment of creation. It is clear that the problem is intimately bound up with the most subtle theological concep-

tions. This can also be expressed in another way. If the universe progresses in the sense supposed according to Carnot's principle, we are led to this strange dilemma, which alone is compatible with the unlimited duration of substance in the past: Either there have been at a very remote epoch infinite differences of temperature and speed in the world which would then have presented phenomena of unimaginable intensity and violence, or the world cannot have always been governed by the laws which govern it now. It takes some courage to ignore these difficulties.

One can understand that one of the most eminent defenders of Carnot's principle and of its universal validity, Lord Kelvin, could only express in an extremely prudent and modest way the conclusions of his profound researches on the subject.

These conclusions are of a nature to appeal to positive minds. They can be summarised as follows: There is at present in the visible world a general tendency towards the dissipation of mechanical energy. This tendency can be considered as constant in time, unless there have been or will be phenomena which are impossible under the present laws of nature. Thus the question of the eternity of the universe is bound up with that of the permanence of the physical laws of nature, a question which at present is insoluble.

Among the phenomena discovered since Lord Kelvin's time, it was once thought that radio-activity would invalidate his conclusions. Not so. The supply of some of the world's energy from radio-active materials will only "prolong the agony." The discovery of radio-activity has mainly proved that there are enormous hidden stores of energy and vitality within the atoms. In spite of this incalculable reinforcemrent, the world will yet, no doubt, experience its "twilight of the gods."

Yet we may perceive a saving life-buoy if we admit the existence of a process the reverse of radio-active disintegration. Everything tends more and more to show that the chemical atoms, the elementary granules of the universe, are perhaps only particular modifications of the substance which we call the luminiferous ether—a hypothetical substance whose existence is yet, doubtless, one of the greatest of human certainties, since without it we could not receive the heat and light of the sun, the source and torch of earth-life. On the other hand, it is possible that in this extremely subtle medium, as in the gases covered by the kinetic theory, even the most improbable arrangements are sometimes realised. Thus perhaps from time to time, in the conditions of temperature and pressure obtaining at the centres of stars, radio-active atoms are regenerated.

In fact, this event need only occur rarely, in view

of the long life of nearly all the chemical atoms and the extreme tenuity of matter in the world. According to recent astronomy, the visible universe only contains a pin's head of matter in each sphere of ether 120 miles in diameter.

At present we cannot maintain the reality of such a phenomenon. Yet it has become possible, if not probable, by certain new directions of thought due to radio-activity. It enables us more easily to assume a certain permanence in the useful energy of the cosmos.

If that is so, the "atomic period" spoken of by Renan, in which molecules were constituted "the fruit of ages of time, of agglutination during thousands of centuries," that period would still be in existence.

Let us not affirm anything, but wait.

For the present we must content ourselves with the somewhat disappointing conclusion that the question of the perpetuity of the universe has hardly advanced during the last 100 years. We have but progressed in finding reasons for modesty and for avoiding dogmatism. We have found precious counsels of wisdom, and a wholesome fear of long extrapolations.

The engrossing interest felt by many people at present in the future destiny of the world is significant. In the life of peoples and of individuals there are hours of moral *malaise* in which despair and lassitude

spread their leaden wings over us. People then dream of annihilation. The end of all things ceases to be "undesirable," and it is almost soothing to contemplate it. Recent controversies on the death of the universe are perhaps the reflection of such an hour of greyness.

CHAPTER VI

DOES THE EARTH TURN?

From Aristarchus to Ptolemy and Newton—The objections of Mach and the doubts of Poincaré—Can we prove that a body really rotates?—Fragility of Newton's arguments—Poincaré and the condemnation of Galileo—Einstein and the relativity of rotations—Finite mass of the universe—A crucial experiment which cannot be tried—Does the earth turn?

I ONCE knew an old *savant* who, when he wished to emphasise an assertion and declare the evidence unshakable, would say: "As sure as the earth turns!"

To-day he would have to recant. For this old problem, this old process of law, which had been considered judged without appeal since Galileo, emerges in an astonishing manner. Everything is once more in question.

The phœnix, that fabulous bird which, burnt to ashes, would suddenly arise and fly away, corresponds, I need hardly say, to no zoological reality. But it furnishes an extremely apt symbol for the evolution of many problems and particularly that of the earth's rotation.

From the remotest antiquity the question has been disputed.

Aristarchus of Samos, about 280 B.C., supposed that

the earth revolved about the sun, and was therefore accused of impiety. Cleanthes of Assos, twenty years later, was, it is said, the first to explain the phenomenon of the starry heavens by the translation of the earth round the sun, combined with the rotation of the earth about its own axis. The explanation was so new, so "revolutionary," that different philosophers proposed, as in the case of Aristarchus, to level an accusation of impiety at its author. It was a way of conducting a one-sided argument.

In spite of all, the new idea made headway. Heraclides of Pontos, Ecphantus the Pythagorean, Philolaus of Croton, Nicetas of Syracuse, had long taught the rotation of the earth about its centre, contrary to Aristotle, for whom the planets and stars revolved round us together with the crystal firmaments to which they were attached.

In spite of the authority of Aristotle and the vogue of Ptolemy's geocentric system, the question remained open. I need only quote the following passage from Seneca:

"We must examine whether the earth is fixed in the centre of the world or whether, the heavens being fixed, the earth turns on itself. Some authorities say that the earth carries us along without our knowledge, and that it is our own movement which produces the apparent risings and settings of the stars. It is an object worthy of our contemplation

to know whether we have an inert dwelling-place or whether, on the contrary, it is endowed with a great velocity, whether God makes everything turn round us, or makes us turn ourselves."

It is known how, in the fifteenth century, the astronomer Purbach revived the crystal spheres of Aristotle, though Ptolemy himself had given them up! It is known how the comets observed by Tycho Brahé blew all this childish celestial glasswork to pieces. It is known also how the immortal canon of Thorn, Copernicus, in his work *De Revolutionibus Orbium Cœlestium*, knocked down the geocentric system of Ptolemy and founded the heliocentric system on positive data. The vicissitudes of the latter in the hands of Tycho, before the great Kepler brought it to its present perfection, are too well known to be recalled here.

But the Aristotelians did not surrender, and their intrigues succeeded in obtaining the condemnation of Galileo, subsequently annulled by Pope Benedict XIV.

For three centuries, the demonstrations and experimental proofs of the rotation of the earth have been multiplied. The aberration of the stars, the movement of the tides, the ellipticity of the terrestrial globe, the existence of the trade winds and their equatorial symmetry, a score of other phenomena observed in nature have brought to the hypothesis of the earth's rotation their cumulative proof, while

any one of them suffices to bring conviction. After observation, experiment has multiplied its proofs in turn. Among these, the most famous are those devised last century by a physicist of the Paris Observatory, named Léon Foucault. The pendulum and the gyroscope of Foucault make the earth's rotation visible to all eyes. All the recent proofs of this rotation have been carefully classified, discussed, and analysed in a fine memoir by Father Hagen, the Director of the Vatican Observatory.

From all this one is irresistibly tempted to conclude with Arago: "Short of denying the evidence, nobody can now doubt a movement demonstrated by an accumulation of so many astronomical and physical proofs."

And yet——

Yet—and here comes in the symbol of the phœnix arising from its ashes—we shall now see that these proofs, so long accumulated and so exactly convergent, are perhaps not proofs after all in the rigorous sense. We shall see that perhaps these ancient controversies are based upon a colossal misunderstanding, a question badly put; and that the whole problem must be considered *ab ovo* and on a new basis.

It is the theory of Relativity propounded by Einstein which has unexpectedly revived this ancient problem which was thought to have been definitely solved.

Relativity again? Yes. "It is not too late to talk about it still." A revolution which upsets our whole conception of the world cannot spend its force in a few weeks; if it did, it would not be what we say it is.

And first of all, a sense of justice, as well as a desire for clearness, obliges me to refer to the great precursors who, like torch-bearers of an advance-guard, preceded Einstein along this new path, and who, before him, were not so sure that the earth turned.

I refer particularly to Mach and to Henri Poincaré.

Einstein himself admits that the work of the Viennese physicist Mach had a preponderating influence upon his mental development.

The problem of the earth's rotation and rotation in general had long occupied Mach and solicited his meditations. Because—as Newton was the first to see—if it is proved that the earth or any given body *really* rotates, it would also prove that *absolute space* exists materially. In other words, if it is proved that a body really rotates, we should necessarily know with respect to *what* it turns, and this thing, this frame of reference, would be an absolutely stationary object in the universe, destitute of any real movement and accessible to our senses.

This is what Newton says on the subject: "The effects by which one may distinguish absolute from relative motion are the forces possessed by turning

bodies which urge them to move away from their axis, for in purely relative movement these forces are zero, while in a true and absolute circular movement they are more or less great in accordance with the quantity of motion.

"If we impart a rotation to a vessel suspended by a string until the cord, being twisted, becomes in some way inflexible; if we then put water into the vessel; and if, after letting the vessel and water come to rest, the string is given freedom to untwist, the vessel will acquire a motion which it will keep for a long time; at the beginning of this movement, the surface of the water will remain flat as it was before the string untwisted; then, as the movement of the vessel communicates itself gradually to the water contained in it, the water will continue to rotate, will rise towards the rim and become concave, as I have proved, and the movement increasing, the rim of the water will rise more and more until, when its time of revolution is the same as that of the whole vessel, there will be a relative equilibrium between the vessel and the water.

"The ascent of the water towards the rim of the vessel marks the effort which it makes to move away from its centre of movement, and in this way *the true and absolute circular movement of the water can be measured* [author's italics]. This is quite contrary to its relative motion, for at first, when the relative

motion of the water and the vase was greatest, that motion excited no effort to move away from the axis. The water remained flat and therefore it had as yet no true absolute circular motion. Afterwards, when the relative motion of the water diminished, the ascent of the water on the rim of the vessel marked its effort to leave its axis of motion; and this effort, constantly increasing, indicated the increase *of its true circular motion* [author's italics]. Finally, this true circular motion was greatest when the water was at rest relatively to the vessel."

To this fundamental argument, which a hasty glance may lend us to think conclusive, Mach replies substantially as follows:

Newton is here in contradiction with his intention only to study the facts, his *hypotheses non fingo*. The absolute space with respect to which he purports to determine the rotation of his vessel is a purely abstract, elusive, and immaterial notion. If we *watch* what happens in this experiment, if we observe and consider with respect to what our vessel filled with water turns, what do we find? We see at once —or we can easily prove—that it is not with regard to the atmosphere, the sensible material medium in which the vessel is placed. Is it with respect to a more subtle medium which fills all space? Newton certainly did not ask himself that question, especially since his emission theory of light did not force him

to assume the existence of this subtle medium which classical physics calls the ether. But if Newton did not raise this question, we can and must raise it. Is it with respect to the ether that the water-vessel turns? Michelson's experiment and similar experiments prove that we cannot know, and that in this respect, as a framework for movement, the ether behaves as if it did not exist.

What is then the real object of reference, the fixed point, the observable thing which enables us to say, while observing the vessel: I see that the vessel turns? On examining this, and reflecting a moment, we see that our final points of reference are the stars. They are so far away as to be practically motionless with respect to each other, and it requires years of delicate astronomical observation to prove the contrary.

It is with respect to the distant bodies of the universe that we finally observe the movement of the water-vessel in Newton's experiment, as we do that of the earth and planets.

If the earth has an absolute motion on its axis, if it really turns *absolutely*, it follows from Newton's argument that centrifugal forces will show themselves, that it will be flattened at the poles, that gravitational acceleration will diminish at the equator, that the plane of Foucault's pendulum and his gyroscope will turn, etc. All these phenomena, according to New-

ton, would disappear if the earth were at rest, and if the heavenly bodies were endowed with an absolute motion giving rise to the same relative motion, i.e. if the Ptolemaic system were true.

It would, of course, be so if we took absolute space for granted. But the case is different, on the basis of Newton's own principles, if we make no hypothesis and only consider the facts. What do we see then? That we can only observe the motion of a body *relative* to other bodies.

And then we find that movements in the universe are the same in the Ptolemaic system as they are in the Copernican system. "The two conceptions," says Mach, "are equally *right*; only the second is simpler and more *practical.* The universe is not given twice, first with an earth at rest and then with a rotating earth, but only once, with only its relative movements determinable. It is therefore impossible to say how things would be if the earth did not turn. All we can do is to interpret in different ways what is given to us."

To put it briefly: (1) Newton asserts that, if the starry sky revolved round a fixed earth, there would be in the latter no centrifugal force such as bulges the equator; (2) Mach asserts that in that case those terrestrial centrifugal forces would exist, with identical effects. The two assertions are absolutely contradictory. Unfortunately, the experiment which alone

could decide between them cannot be carried out. The controversy, as I have explained elsewhere,[1] is therefore purely a metaphysical one—that is, practically insoluble, that is, of no interest—to the physicist.

Mach also remarks that the experiment of the rotating water-vessel shows us that the relative rotation of the water with respect to the vessel does not evoke any apparent centrifugal forces and that these are produced by the relative motion of the water with respect to the mass of the earth and to the other heavenly bodies.

If the wall of the vessel were made thicker and more massive, until it was several miles thick and weighed thousands of millions of tons, nobody can say what the result of Newton's experiment would have been, and whether a centrifugal force caused by the motion of the water relative to the vesesl would have been indicated. All we are able to say is that the observed centrifugal forces seem bound up with a rotation relative to the totality of the bodies in the universe. This totality can, as we have seen, be likened to a single invariable mass on account of the great distances of the stars.

. . . . .

By an intuition which without exaggeration can be termed a stroke of genius, and which, at the time,

[1] See *Einstein et l'Univers*, by C. Nordmann, last chapters.

produced incredulous shrugs among the adherents of classical science, Mach completed his thought in these terms: " A rotation relative to the *fixed stars* produces in a body a force tending to move it away from its axis; if that rotation is not relative to the fixed stars, that form does not exist."

This little phrase, as we shall see, contains the germ of the ideas which, in this essential point, the genius of Einstein has brought to a magnificent harvest.

Besides, in seeking to apply to the planets the mechanical principles discovered by Galileo and his followers, Newton himself was obliged, in ultimate analysis, to refer the planetary movements to the fixed stars, to real objects. Mach says in this connection: " To assert that in connection with the movement of objects we know anything beyond their relation to distant heavenly bodies, a relation furnished by experience, is an act of scientific *bad faith.*" Which shows that even in scientific controversies forcible expressions—too forcible ones—are sometimes used.

The firmest adherents of Newton's *absolute space* themselves feel the need of specifying that, in the end, they mean that sensible, observable space staked out by those distant points of reference, the stars. The most eminent of the present defenders of the Newtonian conception, M. Paul Painlevé, an impenitent

"absolutist," constantly, and in spite of himself, employs the language of Mach, whether he writes: "Let us imagine, for instance, a body without rotation relative to the stars," or "Imagine three directions passing from the centre of the sun to three stars chosen once for all; all the axioms of mechanics are sensibly verified if the movements are thus referred (to those three directions)."

Such words implicitly admit that nothing but a reference of movements to distant bodies, i.e. real objects, is possible.

To sum up, it is evident that both "absolutists" and "relativists" are in agreement, when they make experiments or observations, in referring the law of inertia and all the mechanical laws to the fixed stars as regards space, and to the relative rotation of the earth with respect to the stars as regards time. Only the former consider themselves justified in going farther, in mentally extrapolating their experimental results so as to conceive those elusive entities—useful, no doubt, in calculations—which are called "absolute space" and "absolute time." The latter, on the other hand, cling desperately to observation and perceptible realities, like a captain to his bridge on a stormy night. They refrain from asserting anything as to what the ocean, down there, rolls in its black waters.

Mach summarises as follows his point of view, which

was so long considered paradoxical: "In fact, we cannot *determine* directions and velocities except in a space marked out directly or indirectly by given bodies. . . . Certain opponents maintain that I deny absolute motion because we cannot imagine it. . . . The *representability* and *recognisability* of absolute motion must not be confounded. It is only the second which is lacking. But the investigator of nature only deals with recognisability. What cannot be verified, what has no sensible mark, *has no significance* in science. I do not presume to limit a man's imagination. . . . But we cannot measure an illusory space with any standard." In short, science cannot concern itself with what is possible, but only with what is real, i.e. observable.

Absolute space is possible, but not being observable, it is to the scientific man as if it did not exist.

Mach concludes: "To exclude absolute motion amounts to setting aside that which has no physical significance."

Such, in effect, is the new point of view brought by that mighty precursor into the problem of the earth's rotation.

Though later than the ideas of Mach, those of Henri Poincaré on the rotation of the earth have had a no less profound influence, though on a different plane.

While Mach, an unrivalled experimenter, but a

mediocre philosopher and mathematician, devoted himself to the purely experimental side of phenomena and theories, Poincaré, philosopher and mathematician, viewed the whole problem from a higher level. It was some kind of *à priori* agnosticism or transcendental scepticism which led him to the conclusion that we cannot comprehend anything but relations between things, never the thing-in-itself. It is this bird's-eye point of view which led Poincaré to take his particular step in this matter.

Poincaré imagines a man transported to a planet whose sky is covered perpetually with a thick curtain of clouds, so that he can never see the other stars. On such a planet he will live as if isolated in space. "Such a man," says Poincaré, "can still perceive that his planet turns, either by measuring its polar flattening (ordinarily done by astronomical methods, but also possible by purely geodesic means), or by repeating the experiment of Foucault's pendulum. The absolute rotation of the planet could thus be made evident.

"That is a fact which shocks the philosopher, but which the physicist must perforce accept."

"We know that from this fact Newton deduced the existence of absolute space; I cannot at all adopt this point of view." In another place, Poincaré develops the reasons for his formal opposition to the Newtonian conception. "There is," he says, "no

such thing as absolute space, and all we can conceive is relative motion."

Unceasingly he comes back to this assertion of principle: Relative motion is not only for us a result of experience, but *à priori* every contrary hypothesis is repugnant to the mind. "But," he adds, "if the principle of relative motion is true, why does it only apply to rectilinear uniform motions? It will have to apply with the same force if that motion is variable, or at least, if it reduces itself to a rotation. *But in these two cases the principle is not true.*"

The glory of Einstein is precisely in having answered Poincaré's double question and having shown that his last assertion (italicised by me) ceases to be true if, instead of considering time and space separately, we consider that conglomerate of both, the "interval," as I have elsewhere defined it. In answering, by a stroke of genius, the first of the questions put above by Poincaré, in including variable motion in the principle of Relativity (which became possible by assimilating acceleration to a gravitational field), Einstein, as I have shown elsewhere, brought gravitation under the head of mechanics, and attained the marvellous discoveries now so well known. As regards the second part of the question raised by Poincaré, that concerning rotation, we propose to show now how Einstein made it also pass tamely under the yoke of the principle of Relativity.

Without solving the question, without even seeing how it could be solved, Poincaré, with his admirable intuition, felt that it might be outside the rigid frame of Newton's absolute motion. We know (and I have just recalled it) his ingenious hypothesis of the *savant* operating on a planet separated from the sight of others by a thick layer of cloud. Everybody has read the pages where Poincaré figures such *savants* constructing a system of mechanics, more and more complex, to account for the strange phenomena which are gradually revealed: equatorial bulging of their planet, gyration of cyclones always in the same direction, deviation of the pendulum, etc., an accumulation of hypothesis and complications which makes of their science a more and more confused edifice, until one day a Copernicus arises and cries: "It is much more simple to suppose that the earth turns; it is more convenient to assume that the earth rotates, because the laws of mechanics are thus expressed in much simpler language." "This does not do away with the fact," adds Poincaré, "that absolute space, i.e. the absolute frame of reference for telling whether the earth really turns, has no objective existence."

In connection with this last and very categorical statement by Poincaré, I may be permitted to remark that there would be at least one means (perhaps there are others) of reconciling Poincaré's agnosticism

with the theoretical possibility of verifying whether our earth does or does not really rotate: it is the supposition that our universe is contained in a sphere of isolated ether which is itself mobile in that inaccessible thing which we call absolute space. In this case one might well know that the earth rotates with regard to our universe without implying its rotation with regard to that absolute space. Such an ether of our universe, even if it formed a block, would be itself but a medium in a state of unknown motion with respect to absolute space; it would constitute a privileged space, the particular space of our limited universe. It would then suffice to replace in Newton's pronouncements and in classical mechanics the words "absolute motion" by the words Privileged Motion, and this would eliminate Poincaré's agnostic and philosophical objection.

However this may be, the latter terminates his profound and subtle discussion of the question by his now famous phrase: "Hence the statement, 'The earth rotates' has no sense, since no experiment can verify it; since such an experiment cannot be carried out, nor even designed by the boldest Jules Verne. Or rather, the two propositions 'The earth rotates' and 'It is more convenient to suppose that the earth rotates' have the same single significance. There is no more in the one than in the other."

We remember the press campaign which followed, and in which competence, if not good faith, were conspicuous by their absence: Poincaré felt bound to return to the subject. He denied having intended to rehabilitate in any way the Ptolemaic system or to justify the condemnation of Galileo.

"No," he exclaimed, "there is no absolute space. The two phrases 'The earth turns' and 'The earth does not turn' are, kinematically speaking, equally true. In a kinematic sense, to affirm one and deny the other would be to admit the existence of absolute space. But—there is the apparent daily motion of the stars and heavenly bodies, and, on the other hand, the rotation of Foucault's pendulum, the gyration of cyclones, trade winds, and what not. To the Ptolemæan, all these things are unconnected; to the Copernican, they are all due to the same cause. In saying 'The earth turns' I declare that all these phenomena have an intimate relation, and that is true, and remains true, though there be not and cannot be any absolute space. The truth for which Galileo suffered remains the truth although it may not mean the same to the vulgar, and that its true meaning is more subtle, profound, and rich."

However eloquent this famous proclamation of Henri Poincaré may be, I must confess that it only confirms the famous formula which had unchained the tempest: "The two phrases 'The earth turns'

and ' It is more convenient to suppose that the earth turns,' have one and the same meaning."

Nobody has pointed out, I believe, in this debate, what is really essential: Poincaré has maintained that the adversaries of Galileo may have been right, and that Galileo was also right—that is, that both parties were saying the truth, each in his own language. There was no occasion for a condemnation either way, and it is not right to condemn for his opinions a man who holds the same opinion as his judge, simply because he expresses it somewhat differently.

Unfortunately, Galileo's adversaries were not relativists, any more than Galileo, as it happened. Otherwise they would not have made their mistake.

Yet there were relativists in those days. They were neither Copernicans nor Ptolemæans, but persons who sought to find, for reasons of opportunism or worldly wisdom, the happy medium.

Among these we must number Tycho Brahé, an admirable observer and experimenter, who, however, put forward some entirely absurd ideas on the world system. But among these errors we find some precious pearls. " Our observations," so said the Danish astronomer in substance, " do not concern relative movements: we have no reason to assert that such and such a body is fixed rather than another. It is a question of convention, of the point of view. It is lawful to suppose an observer placed on the sun,

or to suppose him placed on the earth. And since science gives us liberty to choose our point of view, let us adopt the view prescribed by Holy Scripture and take the earth as fixed."

We may agree, in consideration of the troubled times in which Tycho wrote, that the criterion of "convenience" so dear to Poincaré was clearly in favour of the relativistic conception of Tycho as against the absolutist system of the Copernicans. It was more "convenient" for Tycho to differ from, Galileo. He avoided much annoyance by choosing, of two hypotheses equally defensible, the more orthodox. *But Galileo, who was not a relativist, believed that only one of the two hypotheses was exact; his opponents thought the same, but chose the other hypothesis.*

In his reply to those who accused him of attempting to justify the condemnation of Galileo, a reply which, I repeat, did not convince everybody, Poincaré, annoyed at seeing his text quoted for ends foreign to science, expressed himself as follows: "The truth that 'the earth turns,' was placed by me on the same footing as the postulate of Euclid, for example. Was that rejecting it? Moreover, in the same language one might say with justice that the two propositions, (1) the external world exists, and (2) it is more convenient to suppose that it exists, have one and the same meaning. Thus, the hypothesis of the

rotation of the earth would have the same certainty as the very existence of external objects."

Now in 1904 M. Poincaré wrote: "If it is a convention to say that the earth turns, it is equally a convention to say that it exists at all, and both conventions are justified by identical reasons."

It is piquant to see the most impenitent of "relativists," Henri Poincaré, reduced to employing, for his defence against ridiculous accusations, the same language as the most determined of the "absolutists."

Neither must we forget, in dealing with this passage of Poincaré, that "Euclid's postulate" with which Poincaré compares a truth he does not wish to be accused of doubting, is actually contradicted by reality and contrary to the nature of the physical world in which we live, if not to the ideal nature of a particular geometry. I have shown elsewhere[1] how this follows particularly from the curvature of rays of light near material masses, a curvature announced by Einstein and since verified.

It follows that the defence of Poincaré against those who accused him of not being sure that Galileo was right, or at least that his adversaries were wrong—that defence, I say, was much feebler than even Poincaré himself thought it to be. If, returning among us, he would find it so, would he be very sorry? I doubt it.

[1] *Einstein et l'Univers, passim.*

In any case, that is where Mach and Poincaré had left the question of the earth's rotation.

. . . . . .

It was a point at which science could not stop for long, one of those stations at a cross-road where the human caravan cannot halt because of its pressing need to get away from confused by-ways. For the desire to affirm, to advance, to march forward—even to an evil destination—is one of those instincts which most tenaciously hold the poor heart and the poor brain of man. Pascal showed it clearly—but *revenons à nos moutons*.

Mach and Poincaré had, indeed, left the question of the earth's rotation half solved. Their point of view could be finally summarised as follows: we can only observe movements of bodies relative to other bodies, whatever movements may actually exist. Hence the phenomena produced by what we call rotation, and notably the centrifugal forces, cannot be referred to absolute landmarks.

But that being unreservedly admitted, the following questions arose: What is rotation, and what is centrifugal force? What determines them? How, in any case, reconcile their existence and their amount with the principle of the physical relativity of all motion?

To explain the phenomena produced by rotation and particularly centrifugal force, Einstein arrived

with one jump at the very conception which Mach had already sketched out with his profound intuition, viz. the phenomena are caused by " forces of withdrawal " due to distant masses of the universe.

But while Mach limited himself to the cursory statement of that hypothesis, Einstein submitted it to the victorious criterion of calculation and showed that the mathematical solution of the problem of rotation is possible if one admits that the laws of physics have certain general properties.

The novel and fruitful datum which Einstein introduced in this connection is that the laws of physics, the relations which link the events of the universe together, must be identical, " invariant," whatever the point of view of the observer, i.e. whatever his state of motion with regard to the objects seen.

There is something in the Einstein Universe which remains constant and identical for all observers, whatever their displacement. That universal invariant is not the distance which separates in time two very close events; neither is it their distance apart in space. It is a conglomerate of their separation in time and their distance apart, which Einstein calls the " interval " of the two events. The " interval " may be exactly defined as one of the invariable sides of a rectangular triangle, the other side and hypothenuse of which represent respectively the distance in space and the separation in time of the two events

considered, these two sides increasing and diminishing simultaneously according to the speed of the observer.

To this datum Einstein added another essential factor. He found that whenever there is weight or gravitation anywhere, its apparent effects can be annulled by imparting to the observer a suitable variable motion. If you are in a stationary lift and you let go your hat which you hold in your hand, it will fall at your feet. But if at the same moment the lift starts falling freely (an experiment which, in principle, is easily carried out, and which Jules Verne described in his famous conception of a shell falling freely towards the moon), you will find that your hat no longer falls, or rather that it remains at the height of your hand, because you fall at the same time.

In short, we can at any point replace gravitation by a suitable speed imparted to the observer. There is *equivalence* between a gravitational field and an adequate movement of acceleration.

It is on the basis of this "principle of equivalence," together with that of "invariance," that Einstein has solved the problem of universal gravitation.

I have shown elsewhere in some detail—which I need not now elaborate—how he has thus obtained the famous equations which define the trajectories of every material particle abandoned to "itself" in the universe.

These equations contain characteristic coefficients

depending upon the quantity of matter and electromagnetic energy present in space, as well as upon the system of co-ordinates to which the observed phenomena are referred, i.e. the movement of the observer.

As soon as we have defined the system of co-ordinates used (such as geocentric or heliocentric co-ordinates in astronomy) the movement is entirely determined by Einstein's equations. It is hardly necessary here to recall the astonishing discoveries to which these equations have led, notably the anomaly, so long unexplained, of the motion of the perihelium of the planet Mercury.

These equations, already proved in the searching fire of verification as regards Newtonian attraction, must now be applied to the problem of rotation.

That is what Einstein has recently attempted, in the face of technical difficulties which would have discouraged and arrested a score of times anyone but him. Those difficulties, which I may be pardoned for passing over in silence, he has overcome, and success has crowned his efforts and brought the enterprise to a favourable issue.

His calculation is founded entirely on the result reached by Einstein in another way with regard to the old and much-debated question: Is the quantity of matter contained in the universe infinite? In other words: is the material universe infinite?

What is the meaning of the words, The universe is

infinite? From the point of view of Einstein as well as Newton and of pragmatism it means: if I go straight ahead to the end of eternity, I shall never return to my starting-point.

Is this possible? Newton necessarily would say "Yes," because for him space extends infinitely, quite apart from the bodies it contains, whether the number of stars is limited or not.

But Einstein says "No." To the relativist, the universe is possibly not infinite. Is it therefore limited, closed by some railing? No. It is not limited.

A thing can be unlimited without being infinite. For instance: a man moving along the surface of the earth can go round it indefinitely without being stopped by a limit. The surface of the earth, or of any other sphere, may thus be at the same time finite and unlimited. Well then. It suffices to repeat in three-dimensional space what we observe in two dimensions in order to understand how the universe can be both finite and unlimited.

On account of gravitation, the Einstein universe is not Euclidian, but curved, which brings it about that light is propagated through it in a curved line. It is difficult, if not impossible, to represent to one's mind, to *visualise*, a curvature of space. But this difficulty only exists for our imagination, limited as it is by our sense habits, not for our reason, which goes farther

and higher. For it is one of the most frequent of popular errors to suppose that imagination has more powerful wings than reason. To convince ourselves of the contrary, it suffices to compare what the most poetic among the ancients imagined on the subject of the starry vault and what modern science shows us there!

This is then how our problem is stated by Einstein.

Let us neglect for the moment the rather irregular distribution of stars in our stellar system, and let us suppose it to be nearly homogeneous. On what condition will this distribution of the stars under the influence of gravitation remain stable? The reply furnished by calculation is this: The condition is that space has a uniform curvature, that space returns upon itself like a spherical surface.

The rays of light of the stars can travel eternally round this unlimited and yet finite universe. If the cosmos is spherical in this sense, we may even suppose that the rays emerging from a star (such as the sun) will converge to a point diametrically opposite in the universe after traversing it for millions of years.

The consequences of this assumption are strange and grand.

I have just spoken of the millions of years taken by light to travel round the curved universe. Starting from the approximately known value of the quantity of matter contained within our galaxy,

the curvature of the universe and its radius are easily calculated. It is found that this radius has a minimum value equal to 150,000,000 light-years.

It therefore takes at least 900,000,000 years for light to make the tour of the stellar universe. We have seen above that this number is perfectly compatible with those furnished recently by astronomical observations as regards the dimensions of the galactic system and those much greater dimensions obtained when we liken the spiral nebulæ to galactic systems.

Thus, to the relativist, the universe can be unlimited without being infinite. As regards the pragmatist who moves straight ahead—i.e. along what he calls a straight line, the path of a ray of light—he will necessarily rejoin the heavenly body from which he started, provided he has enough time at his disposal. He will therefore say: If that is the nature of things, the universe is not infinite.

The infinite or finite extent of the universe can therefore be, in principle, tested by experiment, and some day we may verify whether the cosmos as a whole and space itself are Newtonian or Einsteinian. Unfortunately, it is a very lengthy experiment, which will encounter practical difficulties. It is, therefore, at present only by its indirect consequences that we can test the accuracy of this conception of Einstein. Let us hold on to this essential fact: *According to Einstein, the total matter contained in our universe,*

the total mass of the stars, is finite, limited, determined. It is by starting from this datum, or from this hypothesis, that Einstein carried through his theory of rotation, and as that theory agrees admirably with facts, it constitutes in itself a weighty argument in favour of the fundamental hypothesis.

Without the hypothesis of the finite quantity of the material masses of the universe, the problem of rotation could not, in fact, be solved by Einstein's equations.

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Just as all matter present in the universe contributes to create at every point the gravitational field existing there, according to Einstein's conception, thus also the inertia of every material point depends upon the influence of other masses external to it. In fact—as Einstein has luminously shown—the inertia and the weight of an object are but two aspects of the same quality. If we find anywhere a part of celestial space filled with approximately homogeneous matter and we are in motion with respect to that matter, the gravitational equations of Einstein have well-defined values of their characteristic coefficients. They define the gravitational field produced by the stars in the system of reference of the non-moving matter. A point at rest remains permanently at rest. If we now transfer ourselves to a frame of reference which *turns* uniformly with

respect to the aggregate masses of the universe, the coefficients of Einstein's equations acquire new values. *And these values, introduced into the equations of motion of generalised Relativity, give exactly the centrifugal forces of classical mechanics.*

If the totality of the masses of the universe were to disappear, perceptible space would also disappear, with its gravitational fields. The centrifugal forces are, therefore, not bound up with an inertia due to the turning body itself, but they are due to the gravitational action of the aggregate mass of the universe, an action *evoked* by the rotation of bodies turning with respect to those masses. Thus the manifestation of those forces is reduced to observable causes. Centrifugal force, no longer a fictitious force as believed by classical science, becomes a visible or at least a sensible force, and is reduced to the forces of gravitation.

On account of the general invariance of physical laws we must admit that the same forces must manifest themselves when our system of landmarks is fixed and the entire universe revolves round it. According to the generalised Principle of Relativity we can consider the earth as turning within a motionless starry sky, just as well as we can regard the earth as fixed.

The two cases, speaking both kinematically and dynamically, are identical and indistinguishable.

If we set in motion one of those roundabouts for babies one sees in country fairs, it does not mean that, to the relativist sitting on the wooden horse, the feeble effort which sets the roundabout in motion suffices to impart a motion of rotation to the entire universe. What the relativist believes is that the motion of the roundabout liberates or brings into action the forces of gravitation originating in the system of co-ordinates which turns with respect to the totality of masses in the universe, and not in the roundabout.

In the same way, in the example given above, the fall of the lift annuls gravity, i.e. liberates a gravitational field equal and opposite to that of the earth.

Similarly, wherever we see signs of what are called inertia efforts, we are probably face to face with gravitational effects of the masses of the universe. If we kick a ball, it acquires an acceleration relative to the universe. This, like a rotation, liberates gravitational forces arising from those masses, and those forces cause an inertia, or resistance to displacement. The same forces must act if the universe is accelerated relatively to the ball. The same force which, in the former case, accelerated the ball, now makes it immovable. Compare with this simple explanation the one given by classical mechanics! All this can be immediately applied to the Foucault pendulum. We shall see that it by no means constitutes a proof

of the "absolute rotation" of the earth. It is not even a terrestrial experiment, but an experiment on the gravitational field of the stars. To simplify—without changing the question—let us examine the typical case when the pendulum is at the Pole and swings about a vertical passing through the earth's axis.

(1) In classical mechanics, there is a system of privileged co-ordinates, the Galilean system, in which (abstracting from gravitation) a body receiving an impulse moves in a uniform direction. The pendulum thus oscillates in an invariable plane with regard to the co-ordinates. Since the earth turns with regard to it, the plane of oscillation must turn with respect to the earth. The Galilean co-ordinates are approximately referred to the stars.

(2) In the Theory of Relativity, a material particle in movement moves also in a straight line in a frame of reference fixed with regard to the masses of the Universe, and the pendulum keeps in an invariable plane. If the earth turns with reference to the stars, we observe from a point in its surface a rotation of the plane of oscillation of the pendulum. The pendulum therefore only proves a relative rotation of the earth and the universe.

If the latter disappears, the question of the earth's rotation loses all meaning. In this case the pendulum would oscillate in a plane invariable with regard to

the earth, the only existing mass, and the plane would not rotate. In classical mechanics, on the other hand, nothing would be changed by the disappearance of all the masses of the universe, and the plane of oscillation would continue to turn.

Unfortunately we have no means of suppressing the heavenly bodies in order to decide between the two doctrines. And since we cannot stop gravitational force by any screen we can only perform Foucault's experiment in the gravitational field of the stars.

The triumphant calculations which incorporated rotation in Einstein's theory have been rendered possible by a new conception of gravitational actions and fields.

Thanks to the Principle of Equivalence, Einstein showed (and his premises have been experimentally corroborated) that all variable relative motion can be compared to a gravitational field and *vice versa.* This enables us to understand what would have surprised us twenty years ago, that there can be very various gravitational fields, very different from that defined by Newton's law; that such a field can be produced by a motion of the observer himself (rotational or otherwise); and that it can produce the singular effects of "centrifugal force." Einstein also shows that the observed gravitation, time, and space are all essentially relative and may change with the

situation and motion of the observer. This enables us to understand how the difficulties which puzzled Poincaré himself have been removed.

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The "forces of withdrawal," to use Mach's expression, those "centrifugal forces" which a distant and considerable mass is supposed to produce in the centre of the cavity it encloses, will, let us hope, some day be placed experimentally in evidence. It would be the finest triumph for this grand conception.

It would be necessary and sufficient to repeat Newton's water-vessel experiment as modified by Mach. As you will remember, Newton felt justified in concluding that centrifugal force was caused by absolute space instead of external objects because the water only curved when its rotation with regard to external objects became rapid, and not at the beginning of the rotation.

It was a bold conclusion, and from an analogous experiment Newton could with the same reason have refuted the law of gravitation.

For if he had held the vessel over the pan of a balance he would have found that it had no effect, though gravitational attraction should have acted upon the equilibrium of the arm and displaced it. If he had concluded that the negative result was due to the fact that the masses were too small to produce

an *observable* effect, though the action might exist—he would have been logical and reasonable.

And the proof of this is that when the experiment is repeated with ultra-sensitive apparatus not possessed by Newton, such as the torsion balance, gravitational attraction can be observed and measured, even between feeble masses.

What is logically true with regard to attraction must be true with regard to centrifugal force. There is no proof that, if Newton's vessel had weighed some millions of tons, there would not have been an observable centrifugal force produced by the relative rotation of the vessel and the water.

To place this force in evidence, if possible, it would be necessary to repeat Newton's experiment with more powerful and more sensitive apparatus.

This has been tried by certain physicists, notably B. and J. Friedländer. They used in their experiments an ultra-sensitive torsion balance suspending a needle, which represented Newton's vessel. The rotating masses were constituted by some enormous fly-wheels from metallurgical and electrical works. The experiment was made in 1896, before Einstein had put forward his equations. The result was negative, the sources of error being too great to be sure of a positive result. But Einstein's theory also shows that the effect could not be made observable in this manner, since the mass even of the greatest

fly-wheel is too small in comparison with the world's masses.

Yet it is in this direction that we must seek—and shall find some day—the experimental demonstration of the centrifugal force produced by a rotating mass at its centre, or by a rotation at the centre of the mass.

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Before concluding, I should like briefly to examine an objection which seems to have occurred to some *savants* who are not yet familiar with the fine profundities of Einstein's theories. This is it: since it comes to the same thing to us whether the earth rotates in the centre of the celestial vault or the latter turns round the earth, let us dwell for a moment on this second view and suppose like Ptolemy that the stars revolve round a fixed earth, and that they make a complete turn in 24 hours. Now we know the distances of many of these bodies, and particularly of the planets. For example, towards the end of 1921 the distances of Jupiter, Saturn, Uranus and Neptune from the earth were about 5 times, 10 times, 20 times and 30 times the distance of the sun respectively (the latter being about 93,000,000 miles). We may conclude from this, that if the heavenly bodies revolved round the fixed earth, then Jupiter, Saturn, Uranus and Neptune, about the end of 1921, passed through distances increasing with their distance from the earth all in the same time, their speeds being

62,000 miles per second for Saturn, 124,000 for Uranus, and 250,000 for Neptune.

If from the planets we pass to the stars, even the nearest ones, we get still more fantastic results. The nearest star is at least 200,000 times farther away than the sun. It follows that to explain the diurnal movement of this star round a fixed earth it must cover in every second a distance equal to 7,000 times the velocity of light in a vacuum (183,000 miles per second), and then follows the objection: Is not this irreconcilable with the theory of Relativity, since, according to that theory, no speed in nature can surpass that of light?

Well, this objection only arises from a misunderstanding. The restricted theory of Relativity only says that at any given point in the universe no speed can surpass the speed of light. It says, in a word, that no speed serving the propagation of a material effect can surpass that of light.

Besides, in the generalised theory of Relativity light possesses no constant speed equal to that usually denoted by the symbol *c*. The value of the speed of light at any point in the universe is a variable which depends upon the value of the gravitational field with respect to a non-Euclidian system of co-ordinates. That allows us to determine from any point in space the speed possessed by light in any other point in space.

Consider, for example, the speed possessed by a ray of light near the surface of the sun. An observer placed in the path of the ray under consideration would find with his scales and pendulums that it still has the same velocity *c*. But an observer placed on the earth and measuring the same speed with the same instruments would find that the speed of the ray diminishes as it approaches the sun. And that produces the curvature—actually observed—of the ray of light passing close to the sun.

In short, what we must never forget is that restricted relativity only applies to any limited region of the universe where the gravitational field can be considered as constant, or zero. But as soon as we consider the observer placed very far from the object observed, it is generalised relativity which must be called in because it alone takes into account the gravitational field which varies from one point to another. Generalised relativity is an extension of that local theory represented by restricted relativity. The former alone must be invoked to the exclusion of the latter as soon as we observe phenomena in which the gravitational field is not where the observer is or where the thing observed is. This has been forgotten by the physicists who have raised the above objection.

What remains is that the generalised theory, just like the restricted theory of Relativity, asserts that

no natural speed can in a given place surpass the speed which light has in that place. That remains true on the hypothesis of the revolution of the stars round the earth.

To sum up, everybody can treat the problem as seems fitting to him, either in describing the phenomena with reference to a rotating earth and a system of co-ordinates linked to the stars, or in describing them with reference to a revolving sky and a system of co-ordinates linked to a fixed earth. The fundamental laws of nature are the same in both cases. This is the essential difference between the theory of Relativity and classical science.

Galileo was right, but his adversaries—I speak from the scientific point of view—were not wrong. Only what neither he nor they knew, and what Einstein and his predecessors have proved to us, is that the rightness of one does not involve the wrongness of the others, and *vice versa*. To employ an image which is but an analogy, the question of knowing whether the earth turns or does not turn is nearly the same as the question of knowing whether the road to Paris from Versailles passes through Sèvres or Viroflay. The truth is that there are two direct routes, one passing through Sèvres and the other through Viroflay, and that everybody according to his convenience, his whim, or his starting-point, may use one or the other.

Thus, finally, the doctrine of relativity gives us a great lesson in mutual indulgence and tolerance in regard to this question, so long, so fiercely, and so uselessly debated. Does the earth turn? Yes, if you wish it. No, if you do not wish it!

CHAPTER VII

CONCLUSION

The two infinites—The foundation of things—Science and morality—The devouring Sphinx—The failure of science—Independence of knowledge and religious sentiment—The divine in the stellar universe—Determinism and divinity.

To the philosopher, the movements of an ultra-microscopic atom are no less astonishing than the gigantic splendours of the sidereal ocean. But since we are feeble creatures we are mostly impressed by what is vast.

We love that fascinating dizziness inspired by limitless horizons. And in the stars, free from accident and disturbing detail, we perceive more readily the simple harmony of the natural laws. A near-sighted person is no good judge of the lines of a landscape, and astronomy, no doubt, is the least short-sighted of human disciplines.

The study of heavenly bodies will always be the favourite haunt of those who love excursions into the land of mystery, whence they return with peace and a little sadness, and where the charm of flowers newly culled makes keener the regret for those one may never reach. Besides, it is more the sense of

beauty than that of truth which leads us to study the heavens. However æsthetic it may be, our present view of the universe is by no means complete. It will surely never be complete, and is it not better so? The ancient Sphinx devoured those who could not guess its riddles. Nowadays, possibly, it would destroy those who had solved them and sounded the depths of things, especially those who dreamed of an ideal!

I hear someone saying: "What interest can lie in the study of those tiny celestial lights which are put out by a tallow candle? When we are caught in the meshes of so many economic, political, and military problems, what matters to us the nature of those little luminous accidents which form the mobile countenance of the world up there? For everything is relative, if our judgment as to what is, or is not, is accidental. If Ovid dared to say that human eyes are naturally raised towards the heavens, he must have been immune against a stiff neck. The tiniest grain of millet would be of greater importance to us."

We do not disagree. But a few cranks must be allowed to see, beyond the problems of eating and drinking, the Unknown, the mystery which assails us on all sides in this strange world, quite as much as the necessity for digestion.

In that singular express train which represents life, between two dark tunnels which, to our feeble view,

mark the limits of its passage, we cannot require of all passengers that they pass all their time in the dining-saloon. We must pardon those who wish, in the course of the journey, to cast a hasty glance at the quaint and curious landscape. And besides, who will say that the study of the luminous vicissitudes of the stars will not some day produce wealth? Electrical industry—to mention only one thing—arose entirely from the amusements of physicists, as abstract one time as astronomical pursuits. And when everybody will be crammed with riches and perishing with plethora, does anyone believe that humanity will have fulfilled its destiny—if it has one? If we wish, like Henri Poincaré, for the advent of that age of gold when gold will no longer tyrannise over us, when all men will be in a state of material satisfaction, it is only or chiefly because on that day a larger number of people will be able to devote themselves freely to the disinterested researches of science, and to untie some of those puzzling veils which hide from us the reality of things. One gets bored with everything except understanding.

But now a voice cries from the other side of the barricade: "What is the good of that? When you have dissected a thousand times all the light of all the stars in the sky, in your grandiose sky which is yet material, do you believe that you will be more advanced or have greater knowledge? The essence and

origin of things, their commencement and their end will still escape you, for the part cannot be greater than the whole, and the little human brain cannot aim at enveloping the whole, of which it is but a purblind portion."

All that, let us admit it, is also true. But if the only result of science were to put us into constantly closer contact with a vaster known world and a still vaster and ever-growing Unknown, it would be none the less useful to mankind.

It would tend to make him more modest, more agnostic, less assertive, dogmatic, and sectarian. It would contribute towards developing in him those smiling qualities of indulgence and moderation which are so necessary to those above all who lead others.

Nobody has yet been indignant at the disagreeable odour of bisulphide of carbon. Science teaches us to look upon our kin from the same angle. Man—and it is the most precise thing we know about him—is only a colloidal oxynitrocarbide of hydrogen with some admixture—to speak chemically. Viewing it thus, we shall no longer be annoyed that it is not one of the physico-chemical properties of this colloid to be the paragon of all the virtues.

Science thus teaches us indulgence towards our kindred. That is no doubt the whole of its ethical rôle, for Henri Poincaré showed a long time ago that science is neither moral nor immoral, seeing that it

speaks in the indicative mood. Morality, on the other hand, speaks in the imperative, and no jugglery can make an indicative into an imperative. To aim at making people virtuous by science is a mockery. Science and virtue are independent variables.

"To be good, man has no need to find a logical basis for his goodness." Quality of heart does not depend upon what sort of spectroscope one uses. That may comfort us for the failure of a preaching science.

Moreover, science teaches us nothing about the Absolute, the "thing-in-itself." The words she employs, Time, Space, Electricity, Energy, clothe very imperfectly those things whose essence we do not know.

But relativists have proved that the only objective reality lies in the relations between things as revealed by the method of experiment. In that objective reality the Absolute is meaningless.

But science, especially astronomy, is not only the best school of agnosticism. It shows us many absorbing and fairy-like things in the universe. "All or nothing" is a bad guide for those in search of knowledge. To know something is not as good as to know all—perhaps. But it is better than to know nothing. We may find a profound and blissful joy in furnishing our dwelling artistically, even if we are sure of never being able to dig up its obscure founda-

tions in the cellar. But we may at least have the additional pleasure to deduce, from signs such as the vibration of the walls produced by passing traffic, certain hypotheses on the nature of those mysterious foundations. And nothing is so amusing as hypotheses which we cannot verify. Nothing so lends itself to dreams, to exaltations towards the infinite, which, according to Plato, constitute love.

That is why men of science worthy of the name are poets. That is why nothing reveals so much poetry as does science.

From this some people have deduced its failure. They did not understand that it was only the failure of a puerile materialism like Haeckel's, who absurdly claimed to have solved the riddle of the universe, but whose solution had no connection with science.

True, this "great engine of marvellous knowledge" has not succeeded in quenching the thirst of suffering hearts who would fain hide the ugliness of the real behind the white veils of the ideal, and are haunted by superhuman dreams. It has not given them definite answers, because it is the servant of Truth, not of Illusion, however sweet. Renan said somewhat resignedly: "Ideal and reality have nothing to do with each other." Science does not tell us what we should find behind the fugitive mirages shown to our eyes by the visible world. If that is failure, then it must be confessed that none of the

human systems which have made the attempt has escaped such failure. We may, after all, rejoice, because that is what makes dreamers and realists tolerable to each other, those who hope and those who verify, "the worshippers and the doubters."

But why should the two points of view clash? In those obscure regions, those limbos beyond the confines of science, beyond the reach of the experimental method, those aspirations may freely flourish which Claude Bernard, somewhat disdainfully, called "the sublimities of ignorance."

One must have a very stoical soul to love truth and moral beauty even though life be only a pain without a morrow. The religious sentiment, by being a sentiment, is placed out of reach of experimental criterion. The old mystical beliefs have saved countless wounded souls from foundering in a sea of despair. There is also that touching poetry which, like a modest flower-pot in a cottage, perfumes and adorns the simple souls who practise the religion of the heart. There is nothing in all this which could be hurt or even touched by the progress of science. That is why one sees among so many savants the growth of a desire both to know and to hope, without a conflict and on different planes. Faith has nothing to fear so long as it flies in the lofty regions of pure sentiment, far from the heavy contacts of experimentation. Metaphysics, beware of physics! Since the material

world, the attainable universe, has limits beyond which imagination is free to roam, science is as indifferent to apologetics as to ethics.

And furthermore. In the very heart of its revelations, science, and especially the science of the heavens, enables us to touch the divine. Evolution and the constitution of the stars, the rhythm which guides the cosmos in a grand harmony, it all obeys, as we have seen, a uniform and inflexible law. The sidereal universe is governed by a rigorous determinism. Modern science, at least, has not yet observed a single phenomenon in the heavens, any more than in other domains, which can be proved to escape from this predestination. I well know that for some time it has been "bad form" to be a determinist. But many will be content to be "stupid" in the manner of Claude Bernard.

The determinism of the world—that is to say, the causal and not accidental connection of phenomena—may prove on reflection to be the sublimest manifestation of the Divine. Yes, the universe is subject to great laws, it is orderly, coherent, harmonious, governed by inexorable laws and not by particular whims. It is by this, rather than its size, that it is grandiose. That is the ineffable mystery, the sublime revelation.

Henri Poincaré had understood it well when he wrote the profound words: "People ask the gods

to prove their existence by miracles. But the eternal miracle is that there are no miracles. That is why the world is divine, because thus it is harmonious. If it were subject to caprice, what would prove to us that it is not governed by accident?"

Truly, the determinate nature of phenomena themselves manifests, in its highest form perhaps, the divinity of the universe.

Such divinity does not, perhaps, agree with the ordinary idea conceived by the slave of his own desires; what does it matter?

The summits of the questions confronting humanity are, like the highest mountains, enveloped in eternal mists. On the first slopes of the Inaccessible, astronomy shows us a magnificent reflex of the Divine. More than any other discipline, it holds us dizzily over those precipices where the physical and the metaphysical touch.

The attraction of the unknown is full of a bitter sweetness. And that is why man on his unending journey will always love that light and trembling thing to which science has lent such a deep significance —the blue light of a star.

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